JMEagler

Volume 29 AUGUST, 1945 Number 8

BULLETIN

of the

American Association *of* Petroleum Geologists

CONTENTS

BULLETIN

of the

AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

OFFICE OF PUBLICATION, 708 WRIGHT BUILDING, TULSA, OKLAHOMA

THE BULLETIN is published by the Association on the 15th of each month.

EDITORIAL AND PUBLICATION OFFICE AND ASSOCIATION HEADQUARTERS, 708 Wright Building, 115 and 117 West Third Street, Tulsa, Oklahoma. Post Office, Box 979, Tulsa 1.

BRITISH AGENT: Thomas Murby & Co., 40 Museum Street, London, W. C. 1.

SUBSCRIPTION PRICE to non-members is $15 per year (separate numbers, $1.50), prepaid to addresses in the United States; outside the United States, $15.40.

CLAIMS FOR NON-RECEIPT must be sent within 3 months of date of publication, to be filled gratis.

BACK NUMBERS, if available, may be ordered from Headquarters. Price list on request.

	Mem.	*Non-Mem.*
Cloth-bound Bulletin, Vols. 12 (1928)–15 (1931) incl., each	$5.00	$ 6.00
Vols. 22 (1938)–24 (1940), 26 (1942) and 28 (1944), each	4.00	17.00

SPECIAL PUBLICATIONS	*Mem.*	*Non-Mem.*
1935. Geology of Natural Gas	$4.50	$6.00
1936. Geology of Tampico Region	3.50	4.50
1936. Gulf Coast Oil Fields	3.00	4.00
1936. Map of Southern California	.50	.50
1938. Miocene Stratigraphy of California	4.50	5.00
1941. Stratigraphic Type Oil Fields	4.50	5.50
1941. Future Oil Provinces, U. S. & Canada	$1.00	$1.50
1942. Source Beds of Petroleum	3.50	4.50
1942. West Texas Permian Correlation Chart	.25	.25
1944. Tectonic Map of United States	2.00	2.00

Communications about the Bulletin, manuscripts, editorial matters, subscriptions, special rates to public and university libraries, publications, membership, change of address, advertising rates, and other Association business should be addressed to

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

J. P. D. HULL, BUSINESS MANAGER

BOX 979, TULSA 1, OKLAHOMA

Entered as second-class matter at the Post Office at Tulsa, Oklahoma, and at the Post Office at Menasha, Wisconsin, under the Act of March 3, 1879. Acceptance for mailing at special rate of postage provided for in section 1103, Act of October 3, 1917, authorized March 9, 1913.

THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS, INC.

Organized at Tulsa, Oklahoma, February 10, 1917, as the Southwestern Association of Petroleum Geologists. Present name adopted, February 16, 1918. Incorporated in Colorado, April 23, 1924. Domesticated in Oklahoma, February 9, 1925.

OFFICERS FOR THE YEAR ENDING MARCH, 1946

MONROE G. CHENEY, *President*, Coleman, Texas
M. GORDON GULLEY, *Vice-President*, Pittsburgh, Pa.
EDWARD A. KOESTER, *Secretary-Treasurer*, Wichita, Kansas
GAYLE SCOTT, *Editor*, Fort Worth, Texas

The foregoing officers, together with the *Past-President*, IRA H. CRAM, Chicago, Illinois, constitute the Executive Committee.

DISTRICT REPRESENTATIVES

(Representatives' terms expire immediately after annual meetings of the years shown in parentheses)

Amarillo: Elisha A. Paschal (46), Amarillo, Tex.
Appalachian: W. O. Ziebold (47), Charleston, W. Va.
Canada: Edwin H. Hunt (47), Calgary, Alberta
Capital: Carl H. Dane (46), Washington, D.C.
Corpus Christi: Ira H. Stein (47), Alice, Tex.
Dallas: Barney Fisher (46), Dallas, Tex.
East Oklahoma: D. E. Lounsbery (46), Bartlesville, J. L. Borden (47), Glenn D. Hawkins (47), Tulsa
Fort Worth: Lynn K. Lee (47), Fort Worth, Tex.
Great Lakes: Robert M. English (47), Mattoon, Ill. Stanley G. Elder (46) Evansville, Ind.
Houston: George S. Buchanan (46), Donald M. Davis (46), A. P. Allison (47), P. B. Leavenworth (47), Houston, Tex.
Michigan: E. J. Baltrusaitis (47), Saginaw, Mich.
New Mexico: Georges Vorbe (47), Socorro, N. Mex.
New York: Gail F. Moulton (47), New York City
Pacific Coast: Eugene H. Vallat (46), Robert T. White (46), Los Angeles, Calif.
Elmo W. Adams (46), San Francisco, Calif.
Rollin Eckis (47), Glenn C. Ferguson (47), Bakersfield, Calif.
Rocky Mountains: Robert L. Sielaff (47), Casper, Wyo.
Shreveport: G. D. Thomas (47), Shreveport, La.
South America: L. W. Henry (47), Caracas, Venezuela
Southeast Gulf: Henry N. Toler (47), Jackson, Miss.
Southern Louisiana: Max Bornhauser (47), Lafayette
So. Permian Basin: George R. Gibson (47), John M. Hills (46), Midland, Tex.
South Texas: Edwin L. Porch (46), San Antonio
Tyler: F. B. Stein (47), Tyler, Tex.
West Oklahoma: Jerry B. Newby (47), Oklahoma City; Arthur M. Meyer (46), Shawnee
Wichita: John W. Inkster (47), Wichita, Kan.
Wichita Falls: Earl M. Stilley (46), Wichita Falls, Tex.

DIVISION REPRESENTATIVES

Paleontology and Mineralogy

John R. Sandidge (46), San Antonio, Texas
Henryk B. Stenzel (46), Austin, Texas

PACIFIC SECTION (Chartered, March, 1929)

GLENN H. BOWES, *President*, Continental Oil Company, 601 W. 5th Street, Los Angeles, California
ROBERT T. WHITE, *Vice-President*, Barnsdall Oil Company, Petroleum Building, Los Angeles, California
VINCENT W. VANDIVER, *Secretary-Treasurer*, Seaboard Oil Company, 417 S. Hill Street, Los Angeles 13
Membership restricted to members of the Association in good standing, residing in Pacific Coast states. Dues: $2.00 per year.

SOUTH TEXAS SECTION (Chartered, April, 1929)

HARVEY WHITAKER *President*, 1409 Milam Building, San Antonio, Texas
MARION J. MOORE, *Secretary-Treasurer*, Transwestern Oil Co., 1600 Milam Building, San Antonio, Texas
Membership limited to persons eligible to Association membership. Dues: $2.50. Annual meeting in October.

DIVISION OF PALEONTOLOGY AND MINERALOGY
SOCIETY OF ECONOMIC PALEONTOLOGISTS AND MINERALOGISTS

(Organized, March, 1927; affiliated, March, 1928; chartered, technical division, April, 1930)
JOHN R. SANDIDGE, *President*, Magnolia Petroleum Company, San Antonio, Texas
HENRYK B. STENZEL, *Secretary-Treasurer*, Bureau of Economic Geology, Austin, 12, Texas

SEND DUES, SUBSCRIPTIONS AND ORDERS FOR BACK NUMBERS TO BOX 979, TULSA, 1, OKLAHOMA. The Society and the Paleontological Society jointly issue six times a year the *Journal of Paleontology*, J. Marvin Weller, University of Chicago, Chicago 37, Illinois, and C. Wythe Cooke, U. S. National Museum, Washington, D. C., editors: subscription, $6.00. The *Journal of Sedimentary Petrology*, W. H. Twenhofel, editor, University of Wisconsin, Madison, Wisconsin, is issued three times a year: subscription, $3.00. Single copies, *Journal of Paleontology*, $2.00; *Journal of Sedimentary Petrology*, $1.50. Society dues: with *Jour. Pal.*, $5.00; with *Jour. Sed. Petrology*, $3.00; with both, $8.00 per year.

AFFILIATED SOCIETIES

(Dates of affiliation in parentheses)

Alberta Society of Petroleum Geologists, Calgary, Alberta, Canada (31). Ian M. Cook, Secy., British American Oil Company
Appalachian Geological Society, Charleston, W. Virginia (31). W. B. Maxwell, Secy., United Fuel Gas Co., Box 1273
Ardmore Geological Society, Ardmore, Oklahoma (36). H. M. Johnson, Secy., Schlumberger Well Surveying Corp., Box 747
Corpus Christi Geological Society, Corpus Christi, Texas (43). Elsie B. Chalupnik, Secy., Barnsdall Oil Co., 604 Driscoll Bldg
Dallas Petroleum Geologists, Dallas, Texas (35). Willis G. Meyer, Secy., DeGolyer and MacNaughton, Continental Bldg.
East Texas Geological Society, Tyler, Texas (32). G. T. Buskirk, Secy., Stanolind Oil and Gas Company, Box 660
Fort Worth Geological Society, Fort Worth, Texas (31). Spencer R. Normand, Secy., Independent Exploration Company
Houston Geological Society, Houston, Texas (32). Charles H. Sample, Secy., J. M. Huber Corp., 721 Bankers Mortgage Bldg.
Illinois Geological Society (39). Gene Gaddess, Secy., Pure Oil Company, Olney
Indiana-Kentucky Geological Society (38). Jess H. Hengst, Secy., Barnsdall Oil Company, Evansville, Ind.
Kansas Geological Society, Wichita, Kansas (31). Edward A. Huffman, Secy., J. M. Huber Corp., 407 First Natl. Bank Bldg.
Michigan Geological Society (37). Manley Osgood, Jr., Secy., Cities Service Oil Co., Box 149, Mt. Pleasant
Mississippi Geological Society, Jackson, Miss. (41). J. B. Wheeler, Secy., Stanolind Oil and Gas Company
New Orleans Geological Society, New Orleans, La. (43). R. R. Copeland, Jr., Secy., The California Co., 1818 Canal Bldg.
North Texas Geological Society, Wichita Falls, Texas (38). John R. Davis, Secy., Superior Oil Co., 807 Hamilton Bldg.
Oklahoma City Geological Society, Oklahoma City, Okla. (31). Carl A. Moore, Secy., Carter Oil Co., 1300 Apco Tower
Panhandle Geological Society, Amarillo, Texas (32). E. W. Sisney, Secy., Cities Service Gas Company, Box 350
Shawnee Geological Society, Shawnee, Oklahoma (31). Marcelle Mousley, Secy., Atlantic Refining Company, Box 169
Shreveport Geological Society, Shreveport, Louisiana (32). L. H. Meltzer, Secy., Union Producing Co., Box 1407, Zone 92
Society of Exploration Geophysicists (32). Cecil H. Green, Secy., Geophysical Service, Inc., Dallas, Tex.
South Louisiana Geological Society, Lake Charles, La. (37). Bruce M. Choate, Secy., Atlantic Refg. Co., Box 895
Southeastern Geological Society, Tallahassee, Fla. (44). R. T. Chapman, Secy., Stanolind Oil and Gas Co., Box 1118
Tulsa Geological Society, Tulsa, Oklahoma (31). Glenn R. V. Griffith, Secy., U. S. Geological Survey, Box 311
West Texas Geological Society, Midland, Texas (38). Alan B. Leeper, Secy., Honolulu Oil Corporation
Wyoming Geological Association, Casper (45), Raymond M. Larsen, Secy., U. S. Geological Survey
Yellowstone-Bighorn Research Association, Inc. (44). W. T. Thom, Jr., Secy., Princeton, N. J.

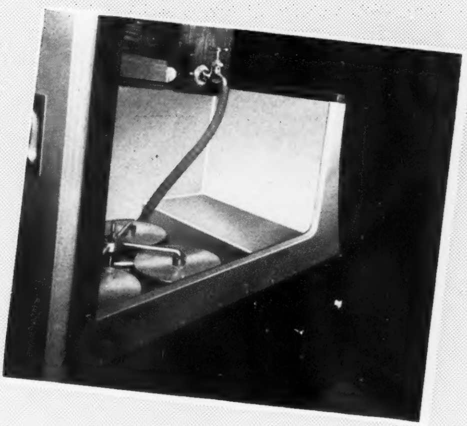

FACTS
ABOUT
GRAVITY METER SURVEYS

National

25-A RECORDING TRUCK

This is the *second* of a series of advertisements prepared to present National's complete line of Seismograph equipment used in National's Seismic Survey Service.

Keep a file of these advertisements; pull carefully from magazines, punch and file in loose leaf binder.



The National 25-A Recording Truck is a modern, efficient and rugged unit, built to withstand the severe field conditions encountered in seismic surveys. The recording body of welded steel construction is separated into a recording compartment and developing compartment, allowing efficient processing of records without impeding recording operations. The recording compartment in the forward part of the body houses the assembly of recording instruments which are mounted in a shock absorbing rack. A total of 24 type 25-A amplifiers, a mirror galvanometer type recording oscillograph, a special compositing panel, power panel, etc., comprise the recording instruments which are compactly arranged so that all necessary controls are readily accessible from a single position. The developing compartment is a small, light-tight room with a sliding door. This room contains developing sink, storage space for supplies, and darkroom lights.

The recording unit includes ample storage space for supplies and tools, a built-in water tank, and a special fan belt driven generator for charging equipment storage battery.

ICATIONS

NATIONAL 25-A RECORDING UNIT

Truck: 1½-ton Ford or Chevrolet, two-speed rear end.

Recording Body: Welded steel construction containing operating compartment, developing compartment, working platform, cable reels, seismometer rack; dimensions—73"x52"x101¾".

Operating Compartment: Dimensions—41"x62½"x50¾".

Developing Compartment: Dimensions—26¾"x43"x50¾".

Cable Reels (Two): Dimensions—24" diameter, 20" width, 9" core.

Seismometer Racks: Capacity—48 seismometers.

Wt. of Truck Complete with Instruments: 7,750.

ICAL COMPANY, INC.

SEISMOGRAPH EQUIPMENT


Spencer Instruments
IN PEACE TIME
MICROSCOPES:
Research School Stereoscopic
Medical Industrial Polarizing
Microscope Lamps Spectrometers
Refractometers Colony Counters
Magnifiers Microtomes
Haemacytometers Colorimeters
Accessories
DELINEASCOPES:
Lantern Slide Film Slide Color Slide
Opaque Object Combination
IN WAR TIME
the instruments shown above
AND
Binoculars Azimuth Instruments
Telescopes Anti-aircraft Gunsights
Periscopes Aircraft Gunsights
Torpedo Directors Tank Sights
Telescopic Alidades
—for our Armed Forces and
War Production
American Optical
COMPANY
Scientific Instrument Division
Buffalo 11, New York


WORLD'S DEEPEST PRODUCER
1. ELECTRICALLY LOGGED
2. SIDE WALL CORED
3. TEMPERATURE SURVEYED
4. DIRECTIONALLY SURVEYED
5. DIP METERED
6. GUN PERFORATED
SCHLUMBERGER ...ALL THE WAY!
SCHLUMBERGER WELL SURVEYING CORPORATION
HOUSTON, TEXAS

Bulletin Advertisers

PROFESSIONAL CARDS

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

Articles for September *Bulletin*

Recent Sedimentation and the Search for Petroleum
By W. C. Krumbein

Résumé of Facts and Opinions on Sedimentation in Gulf Coast Region of Texas and Louisiana
By L. W. Storm

Marine Jurassic Formations of Sweetgrass Arch, Montana
By W. A. Cobban

Pre-Permian Axis of Maximum Deposition in West Texas
By Jackson M. Barton

Volume 29 Number 8

BULLETIN
of the
AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS

AUGUST, 1945

PETROLEUM GEOLOGY OF COLOMBIA, SOUTH AMERICA[1]

J. L. ANDERSON[2]
Baltimore, Maryland

ABSTRACT

Colombia is located in the extreme northwestern part of South America and falls within the tropical zone. One half of the country consists of mountains and valleys while the other half is plains or "llanos." Travel within the country is usually difficult except between the larger cities which are connected by airplane. Three prominent ranges of mountains with their intermontane valleys comprise the mountain province. The Magdalena Valley between the eastern and central ranges is at present the most important petroleum-producing section. Two geosynclinal areas of deposition are recognized. The North Andean geosyncline located in the eastern part of the country and whose axis trends N. 25°–30° E. was the locus of deposition of Cretaceous and early Tertiary sediments. At the close of the Cretaceous, downwarping produced the Tertiary Bolivar geosyncline between the present western and coastal ranges. This geosyncline was terminated in the late Tertiary Andean revolution. Tertiary deposits are also widespread along the north coast of the country as well as in the Magdalena Valley. Overthrust structures are common in the eastern portion of the country. Petroleum occurs on asymmetric anticlines which are in places complexly faulted.

Six potential petroliferous provinces may be recognized. Of these, the Magdalena Valley and the Barco Concession located in the Southwest Lake Maracaibo drainage area are at present the most important producing regions. Considerable activity is being carried on both in the Llanos and in the North Coast areas.

Colombia normally ranks about eighth in world production with approximately 25,000,000 barrels a year output. In South America, it is second to Venezuela, whose production is nearly ten times as great, and slightly ahead of Argentina and Trinidad. The country is now being systematically studied by both geological and geophysical means.

INTRODUCTION

Although petroleum has been produced in Colombia since 1918, it was not until 1936 that serious efforts were made to find oil in the more remote parts of the country. The physical character of this tropical country with its high mountains, swampy rainfall jungle valleys, and isolated great plains largely discouraged both geological and geophysical work. The advent of the present war with its great demands on our petroleum reserves changed the entire outlook and now Colombia is undergoing a very systematic study by both geological and geophysical methods.

[1] Delivered before affiliated societies in the Distinguished Lecture series of the Association, October–November, 1944. Manuscript received, March 30, 1945.

[2] Assistant professor in geology, The Johns Hopkins University. Formerly geologist, Tropical Oil Company, Colombia, S.A.

FIG. 1.—General map of Colombia showing location of more important cities and towns.

Location and nature of area.—Colombia lies entirely within the tropical zone, extending from 4° S. Lat. to about 12½° N. Lat. (Fig. 1). Most of the country, however, lies between 1° and 12° above the equator and the present producing areas are found at about 6½° N. Lat. The area also falls within 67° and 79° W. Long.

The country is bounded on the north by the Caribbean Sea and possesses 641 miles of coastline facing this body of water. The cities of Cartagena, Barranquilla, and Santa Marta are principal ports for ocean traffic but only Cartagena and Barranquilla are important for the petroleum industry. Cartagena is less favorably situated than Barranquilla because goods must be transshipped by rail to the Magdalena River port of Calamar while ocean steamers can dock at Barranquilla and material can be placed directly on river steamer. Barranquilla is the northern terminus of the Colombia airlines and also the port of entry for passengers of the Pan-American Airways from the United States. Northwest of Colombia lies the country of Panama and on the west is the Pacific Ocean. Colombia possesses 468 miles of coastline facing the Pacific and the city of Buenaventura is the only important port on the west coast. This city does not serve the petroleum industry but is an important port both for the mining industry and the coffee trade. South of Colombia lie the countries of Ecuador and Peru and on the east are found the countries of Venezuela and Brazil.

Colombia is served by both boat and plane. Barranquilla is 1,800 miles from New York, 3,229 miles from Los Angeles, and 3,561 miles from San Francisco *via* the Panama Canal. Planes of the Pan-American Airways fly between Barranquilla and Miami, Florida, in less than 12 hours. Normally, Colombia is also served by European steamship lines.

Of all the interior cities, the capital city of Bogotá is the most important. It is located, like many of the interior cities of Colombia, on a table-land in the eastern Andes Mountains at an elevation of 8,727 feet. Before the advent of the airplane into Colombia in 1920, passenger travel from Barranquilla to Bogotá consumed from 8 days to a month, depending on the amount of water in the Magdalena River. Now passengers and mail are flown from the Carribbean coast to Bogotá, a distance of 450 air miles, in 2½ hours. The population of Bogotá in 1938 was 330,312 and the city is the headquarters of the petroleum companies. The town of Cucúta located in the northeastern part of the country near the Venezuelan border serves as the headquarters of the Barco Concession. All other large cities such as Medellín, Quibdó, Manizales, Ibaqué, Cali, Popayán, and Pasto are located in the central and western part of the country and do not serve the petroleum industry. Travel within Colombia is extremely difficult due largely to the configuration of the country. The Magdalena River is the main artery of commerce and most of the railroads, of which Colombia has 1,918 miles, serve as feeders to the river. Travel on the Magdalena River is by means of shallow-draught boats (Fig. 2). The port of Buenaventura on the Pacific coast is connected with the Cauca valley cities of Cali, Popayán, and Manizales by railroad

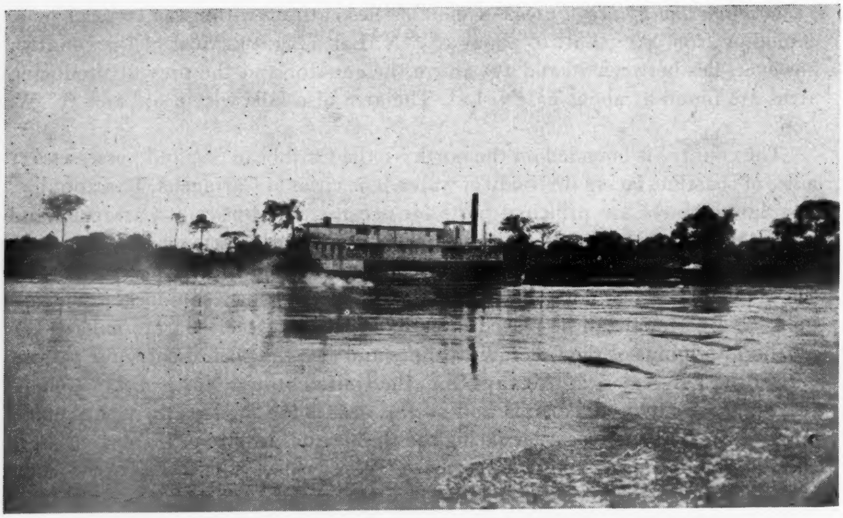


FIG. 2.—Travel on Magdalena River is by stern-wheel, shallow-draught boats.

FIG. 3.—Native dug-out canoe on Magdalena River.

and a cable railway connects Manizales with the Magdalena River port of Honda. The Magdalena River port of Puerto Berrío is connected with the Cauca river through the city of Medellín. Bogotá, the capital, is linked with the Magdalena River by railroad and also has several lines running both north and south in the eastern range. With the exception of the railroad between Bucaramanga and Puerto Wilches on the Magdalena, the line between the Magdalena port of Calamar and Cartagena, and a short line from Santa Marta southward, there are no railroads in the central and northern portions of the country. There are relatively few good highways in Colombia and most of them are found in the highlands. Bogotá is connected with Caracas, Venezuela, by the Transandian or Pan-American highway. It is also possible to reach Quito, Ecuador, from Bogotá by road. Geological and geophysical work especially in the Magdalena Valley area has to be conducted over trails cut through virgin jungle and along the rivers and streams. Both in the valleys and in plains, the native mule or "burro" is used as a beast of burden.

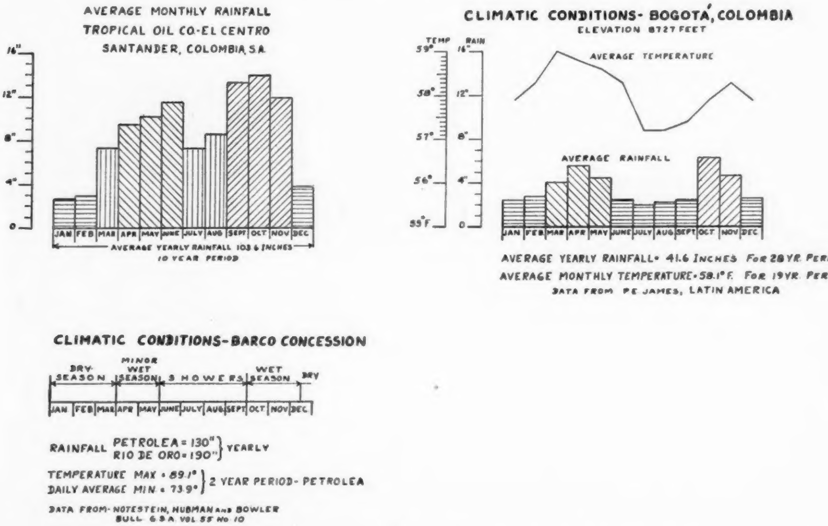


FIG. 4.—Graphs showing rainfall and temperature, Colombia, S. A.

Climate conditions, especially the amount of rainfall, are important factors in the search for and the production of petroleum in Colombia. In the Magdalena Valley as well as in the Southwest Lake Maracaibo drainage area, field work is largely controlled by the amount of precipitation. Two wet seasons are known in these areas, one in the fall and the other in the spring (Fig. 4). In the middle Magdalena Valley at the El Centro camp of the Tropical Oil Company, records show that over a 10-year period there was an average yearly rainfall of 103.6

inches. According to Notestein, Hubman, and Bowler (1944) the average yearly rainfall of the Barco area was 130 inches at Petrolea and 190 inches at Río de Oro. The average daily temperature in this region, according to these authors, is 89.1°F. maximum and 73.9°F. minimum. The fall rains are usually more severe and field work, especially in the Magdalena Valley, can hardly be carried on (Fig. 5). The months of December, January, February, and March constitute the main dry season and are well suited for field work. The months of July and August constitute the minor dry season which follows the less severe spring rainy period.

In contrast with the climatic conditions of the middle Magdalena Valley are those of Bogotá. The distribution of wet and dry seasons is similar to that of the

FIG. 5.—Flood waters during rainy season on tributary of Magdalena River.

Magdalena Valley and the eastern flank of the eastern Andes, but the amount of precipitation is not as great. Bogotá has an average annual rainfall of 41.6 inches and an average monthly temperature of 58.1°F. (Fig. 3). Although the climate of Bogotá has been compared with that of the spring in the temperate zone, actually the seasonal variation is only 1.8°F.

Along the northern coast of Colombia, the average annual precipitation varies from east to west. In the Guajira Peninsula it is between 10 and 20 inches, increasing to more than 80 inches in the valley of the Atrato River. In the llanos or plains region in the southeastern part of the country, the average is on the whole more than 80 inches annually.

Malaria, dysentery, and typhoid fever, common ailments of all tiopical coun-

tries, are to be guarded against. Dysentery can largely be controlled by eating only well cooked food. Inoculations can be taken against typhoid but it is wise to drink only water that has been boiled or treated chemically. Malaria is more difficult to control especially in the jungle country. Mosquitoes are always present and one is fortunate not to contract this disease if he is long exposed.

The inhabitants of Colombia are primarily a mixed race. This is especially true in the lowland areas where the people are of European, Indian, and Negro blood. It has been estimated that about one half of the population is mestizo or hybrid. The official language of the country is Spanish but English in many instances is spoken.

Physiography

The diversified topography of Colombia allows it to be divided into two major physiographic provinces (Fig. 6). The first includes the mountains and intermontane valleys and is situated in the western half of the country. The second is the great plains or "llanos" located in the eastern and southeastern sections. The area of Colombia is 439,828 square miles, approximately 240,000 square miles of which lie east of the eastern range of mountains or in the llanos region while 200,000 square miles constitute the mountain province.

Colombia has a population of 8,701,816 according to the 1938 census. Of these, only approximately 200,000 are found in the llanos area. More than 8,500,000 people, the bulk of the population, are found in the mountain province in the western part of the country (Fig. 1).

Andean Mountains and Valley Province.—Four mountain ranges, including a variety of geological structures, are known in Colombia. The westernmost range known as the Cordillera de la Costa or the Serranía de Baudó is the lowest and narrowest. This range, whose highest point is less than 6,000 feet, extends from Buenaventura northward into Panama. Although low, the erosion caused by abundant rainfall has produced a very rugged topography (James, 1942).

The Colombian Andes, united in the vicinity of the city of Pasto near the Ecuadorian border, emerge as three ranges trending in a general northeasterly direction. The westernmost range known as the Cordillera Occidental or western cordillera is relatively low. According to Irisarri (1929b) its average height is between 6,000 and 12,000 feet. It divides into two branches at its northern end and plunges beneath the Tertiary deposits of the north coast. Lying between the Serranía de Baudó and the Cordillera Occidental is the 25–30-mile-wide structural valley of the Atrato and San Juan rivers. The Cordillera Central or central cordillera contains some of the highest peaks of the Colombian Andes and is more than 500 miles long and 30 to 40 miles wide. Snow-capped active, semi-active, and extinct volcanoes rise to over 18,000 feet in the southern part of the range, but toward the north the Cordillera Central loses its altitude and plunges beneath the Tertiary deposits near the town of El Banco. The Cordilleras Occidental and Central are separated by the structural trough through which the Ríos Cauca

FIG. 6.—Relief map showing physiographic provinces of Colombia. (From advertisement of Consorcio Cervecerias Bavaria, S. A.)

and Upper Patía flow. The Cordillera Oriental or eastern cordillera is separated from the Cordillera Central by the structural valley of the Río Magdalena. The eastern cordillera is the youngest and the longest of the Colombian Andes. It is formed by folded sedimentary rocks over a crystalline core and in the southern part of the country attains elevations of over 13,000 feet. North of Bogotá in the vicinity of Tunja, the Cordillera Oriental is 145 miles wide and between these localities more than half the width is a plateau representing the filling of old lake basins. The elevation of this region is between 8,100 and 9,800 feet above sea-level but there are large areas called "paramos" which extend to elevations of more than 17,000 feet. Near the Venezuela border the Cordillera Oriental divides, one branch continuing northward as the Sierra de Perijá, the watershed between the Río Magdalena and Lake Maracaibo, and the other, trending in a north-easterly direction and known as the Cordillera de Mérida, is separated from the Cordillera Oriental of Colombia by the structural depression of San Cristóbal.

At the northern end of the mountain province lies the coastal plain of northern Colombia. This area is characterized by low grassy plains, swampy areas, and hills whose elevations are usually under 1,000 feet. The region is traversed by the Ríos Magdalena, Cauca, San Jorge, and Sinú and near the rivers tropical forests are common. In the northeastern portion of the country and cut off at the Caribbean coast by the Ocoa fault is the Sierra Nevada de Santa Marta whose snow-capped peaks rise to about 19,000 feet. This range is separated from the Sierra de Perijá by the structural valley of the Río Césár.

Llanos Province.—East of the Cordillera Oriental lie the vast low grassy plains of eastern Colombia. Several large rivers and innumerable small streams flow eastward and southeastward into the Orinoco and Amazon drainage. The elevation of this region is about 700 feet above sea-level and is one of the most inaccessible and sparsely settled areas of Colombia. To the east of the llanos and south of San José del Guaviaré (Trumpy, 1943) are found the igneous and metamorphic rocks of the Guayana Shield.

Geological History

PRE-CRETACEOUS

Pre-Cretaceous rocks have no direct relation to the occurrence of petroleum in Colombia except that they form the basement upon which the post-Cretaceous sediments were deposited. Pre-Paleozoic rocks, such as nepheline syenite containing magnetite have been described by Trumpy (1943) from south of San José del Guaviaré in the llanos area southeast of Bogotá (Fig. 1). In the Garzón massif of the eastern cordilleras, he also describes alkali feldspar gneisses and pegmatites containing molybdenium, assigning them to the pre-Paleozoic. The amphibolites near Medellín in the Cordillera Central are considered Archean by Scheibe (1933b). Amphibolites and gneisses of probably pre-Paleozoic age have been reported from the Sierra Nevada de Santa Marta (Trumpy, 1943). Shaly, micaceous sandstones, quartzites, thin limestones forming the Güéjar series,

occurring in the Macarena and along the Uribe trail of the llanos area, have been assigned to the Cambro-Ordovician on the basis of their fossils (Trumpy, 1943). Ordovician graptolites were obtained by Harrison from shales in the Cordillera Central near Cristalina, not far from Malena, on the Puerto Berrío-Medellin railroad (Harrison, 1929). At Florestá (Boyacá) Olsson and Ramirez (Dickey, 1941) discovered fossils in soft shales whose age has been determined by Caster as Lower Devonian (1940). These fossils have been studied and described also by Royo y Gomez (1942d). In the valley of the Cesâr River, Trumpy (1943) describes conglomerates and cherts containing a Middle Devonian fauna. Stutzer (1934h) and Kehrer (in Trumpy, 1943) describe Carboniferous strata near Gachalá on the east flank of the Cordillera Oriental, east of Bogotá. Dickey (1941) and Trumpy (1943) describe upper Carboniferous limestone, red and black shales and sandstones which were first found by Merritt at Bucaramanga. In the northern part of the Sierra de Perijá at Manuare, fossiliferous Carboniferous limestone is found as float in the streams. Fossiliferous brown sandstone, shale, sandy shale, and some limestone are reported by Trumpy (1943) from Cerro Cerrejón in the Ranchería Valley. Fossiliferous dolomitic limestone with layers of black chert all of Permian age have been reported by Trumpy (1943) east of Manuare in the Sierra de Perijá. In the Cordillera Central at Payandé, west of Girardot, Trumpy (1943, p. 1297) describes porphyritic red-beds, limestone chert, partly sandy and siliceous with intercalations of brown partly tuffaceous cherts as the Payandé formation. Fossils from the limestone indicate a Triassic age. The Payandé is uncomformably overlapped by Lower Cretaceous (Trumpy, 1943, p. 1299). Marine Lias is known from the El Banco area and the Cesâr Valley (Trumpy, 1943, pp. 1299–1300). Here fossils have been found in black shales and thin limestones in the lower part of a series which contains red-beds, shales, sandstones, conglomerates with thick acid flows, tuffs, and agglomerates. This series is intruded and overlain by volcanic breccias and acid intrusives and in turn is overlain by the Lower Cretaceous.

GIRÓN SERIES OF MIDDLE MAGDALENA VALLEY

The name Girón was introduced by Hettner (1892) for a thick (10,000–12,000 feet) red-bed series containing conglomerates, red and green sandstones and shales near the town of Girón on the west flank of the Cordillera Oriental. From this original description, Hettner obviously included within his Girón, non-fossiliferous red-beds belonging to the Carboniferous of Bucaramanga (Trumpy, 1943, p. 1300) as well as conglomerates, sandstones, and shales carrying Neocomian fossils (Hedberg, 1940). This confusion largely arose, as pointed out by Trumpy (1943, p. 1300), from the fact that Karsten (1886) reported Lower Cretaceous ammonites in red-beds near Urumita in the upper Cesâr Valley on the west flank of the Sierra de Perijá. Oppenheim (1940) and Dickey (1941) have given good descriptions of the Girón and have pointed out the relations to both the underlying red-bed series and the overyling conformable fossiliferous sandstones,

shales, and limestones of the Cretaceous. Notestein (in Schuchert) has also noted that confusion in the use of the term Girón and reveals that at Los Santos the basal Cretaceous consists of massive pink and gray sandstones and is underlain unconformably by a thick series of red and green sandstones, siltstones, and some conglomerates which are the true Girón. The basal Cretaceous is derived from the red Girón and hence resembles it in color. Kehrer (1936) described in detail the Cretaceous section southeast of Bogotá, the lower part of which he calls "Girón," thus adhering to the original definition of Hettner. The true Girón, according to Oppenheim (1940), consists of about 500 meters of red, conglomer-

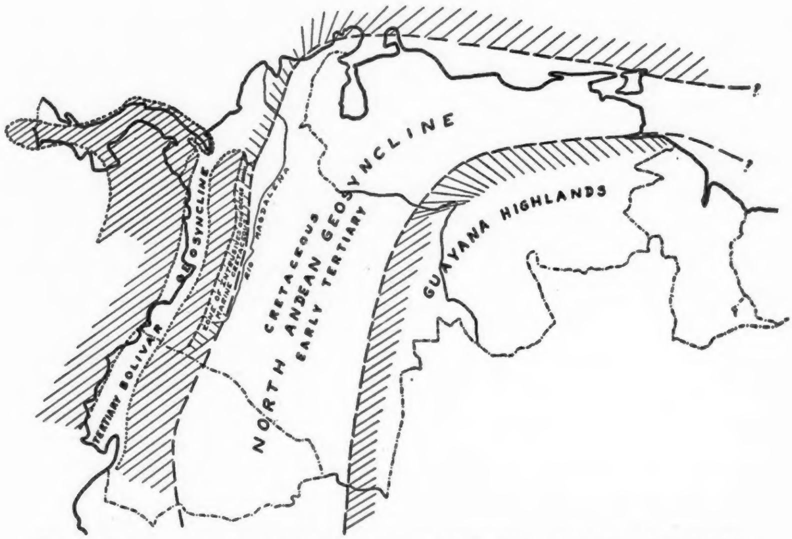


FIG. 7.—Showing general location of Cretaceous and Tertiary geosynclines in Colombia.

atic sandstones and clay shales transgressing over the metamorphic basement and correlated with the Jurassic La Quinta formation in southwestern Venezuela. It is overlain by Lower Cretaceous limestones and sandstones of the Cocui series which are equivalent to the Tomon series or Uribante beds of Venezuela (Oppenheim, 1940). Trumpy (1943) records over 2,000 meters of sandstones, grits, conglomerates alternating with red and green siltstones and shales of Girón age in the gorge of the Lebrija River.

GEOSYNCLINES AND BORDERLANDS

The loci of deposition of the Cretaceous and post-Cretaceous sediments are confined in general to two geosynclines. These areas of deposition have been called the North Andean and the Bolívar geosynclines (Fig. 7).

North Andean geosyncline.—This area, containing many connecting basins of sedimentation, had its beginning in the early Mesozoic. At the close of the Jurassic, crustal disturbance, revealed by local unconformities, transgressive nature of the Cretaceous with thick basal conglomerate containing pebbles of earlier Mesozoic rocks, and difference in facies between early Mesozoic and Cretaceous sediments prepared the way for the deposition of the vast deposits of Cretaceous age (Hedberg, 1940). Differential subsidence began in northern South America over a broad area bounded on the south and east by the Guayana shield or borderland which was a positive element through Mesozoic and Tertiary time. The basin was bounded on the north by the Parian borderland of Venezuela and the borderland of Santa Marta which extended from the Guajira Peninsula of Colombia to eastern Panama (Schuchert, p. 635). The borderlands of the west, the Chocó of Schuchert, the Macizo Pacífico (Pacific Massive) of Steinmann, and Buckhardtland of Von Ihering, included a mobile zone which at least in part coincided with the present Cordillera Central, all of the Cordillera Occidental, and extending outward into the eastern Pacific (Olsson, 1932). The general trend of the geosyncline was therefore nearly east-west in Venezuela (Venezuelan geosyncline), the major axis of subsidence according to Hedberg (1940) probably coinciding with the Caribbean Cordillera. In Colombia, the major axis of subsidence coincided with the Cordillera Oriental and the trend was nearly northeast-southwest. Marine Cretaceous deposits extended southward into Ecuador and Peru.

Deposition continued throughout Cretaceous and well into Tertiary. No pronounced orogeny but broad epeirogenic movements marked the close of the Mesozoic in the North Andean basin. The sea withdrew slowly from the south toward the north, caused by a gradual shrinkage of the basin. This withdrawal was marked by a lithologic change in the character of the sediments. It was not until the Eocene that pronounced orogeny took place, separating the North Andean geosyncline into several intermontane troughs, the geosyncline itself passing out of existence.

Bolívar geosyncline.—The initiation of folding and uplift which began at the close of the Cretaceous along the Andean geosyncline was compensated by a down-warping toward the west resulting in the formation of a Tertiary geosyncline (Olsson, 1932). This area of deposition was bounded by land whose eastern limits on the west were the Coastal Cordillera of Colombia and which extended from eastern Panama southward into Ecuador (Fig. 7). On the east, it was bounded by land coinciding with the Cordillera Occidental of Colombia. The geosyncline coincided with the valleys of the San Juan and Atrato rivers extending eastward along the north coast of Colombia and up the Magdalena Valley as far as El Banco. There was an opening, according to Olsson, in western Ecuador which allowed a migration of faunas both from the Pacific and from the Caribbean. Olsson points out that the Tertiary faunas of northern Colombia possess strong Pacific elements while Caribbean types are known along the west coast (Olsson,

1932, p. 53). The Bolívar geosyncline was flooded during late Eocene, late Oligocene, and the entire Miocene time. Crustal movements causing the foundering of the Pacific foreland during Miocene-Pliocene time changed the geosyncline into land.

Structural Development

General.—The present configuration of Colombia had its beginning in the Mesozoic and culminated in the profound orogeny of the late Tertiary. The high mountain ranges and intermontane valleys were the results of several periods of orogeny. From a structural point of view therefore, two principal zones may be recognized, one consisting of highly folded and faulted sedimentary rocks found in the extreme eastern and western parts of the country, and the other, the faulted and folded metamorphics, intrusives, and volcanoes of the central and western ranges.

Cretaceous and post-Cretaceous sedimentary rocks are found chiefly in the Cordillera Oriental, the Magdalena Valley, and the valley of the San Juan and Atrato rivers. Tertiary sediments are also known from the Caribbean coastal area and the middle and lower Cauca Valley.

The character of the deposits varies depending on the character of the basins at the time of deposition. In the Cordillera Oriental, in what was a part of the North Andean geosyncline, conglomerates, sandstones, black fossiliferous, pyritic shales, and bituminous, fossiliferous limestones are common. Coal seams associated with the shales and sandstones are known. Granitic rocks are seen in places in the core of the Cordillera Oriental. The Cretaceous and Tertiary sedimentary rocks of this range have a total thickness in places of about 50,000 feet.

In the upper and middle Magdalena Valley, conglomeratic sandstones and shales are common while in the lower valley and in the coastal area fossiliferous shales and limestones are known.

Tertiary sands and shales are found in the valley of the San Juan and Atrato rivers and also in the middle and lower Cauca Valley where they contain coal measures and are in part fossiliferous. The Cordilleras Central and Occidental and the Serranía de Baudó have a geological history distinct from that of the Cordillera Oriental. Pre-Cretaceous sediments and Cretaceous limestones have been reported from the Cordillera Central, but the principal rock types are acid and basic intrusives and extrusives, gneisses, and crystalline schists. The Cordillera Occidental is characterized by granites, crystalline schists, black slates, crystalline limestones, and a great development of andesite porphyries and related volcanic rocks. The Serranía de Baudó consists of old igneous and metamorphic rocks overlapped by Tertiary deposits.

Considered in a broad sense, therefore, the rocks of Colombia may be divided into two large categories. The first type is represented by the sedimentary rocks of the eastern and northern parts of the country and the second type by the igneous and metamorphic rocks of the western part. The over-all structural pattern

is thought to have been controlled largely by the distribution of the various rock types.

Cordillera Oriental and Magdalena Valley area.—This region is the best known geologically of any in Colombia and is the area of sedimentary rocks. Most workers have considered the Magdalena Valley a graben bounded on both sides by normal faults (Stille, Stutzer, Scheibe, Grosse, Harrison, Anderson, *et al.*). Harrison (1929, p. 399) refers to it as "a trough-like depression or graben in which the Magdalena River flows, from Natagaima 3°37′ N., 75°7′ W., to El Banco 9° N., 74° W., a distance of about 300 miles." The graben is stepped, bounded by a reticulation of faults and is more than 4,000 feet deep. He also considers the valley of the Río Cesár a continuation of the "north-south ditch to the north of El Banco" (p. 399). Harrison further speaks of the Cordillera Oriental as a "zone of strong folding and overthrusting toward the east" and assigns a late Cretaceous age to the principal movements (p. 401). He postulates strong erosion in the post-Cretaceous and a new cycle of sedimentation starting in the upper Eocene. His statement, "Further movements occurred later which caused folding and faulting, but, so far as is known, did not cause overthrusting" (p. 401) is not substantiated by present information. Later work connected with the search for petroleum has shown that overthrusting involving Upper Tertiary beds is common in the valley. Anderson (1927, p. 639) refers to the findings of Stille (1907) who describes the valley as an "interandean graben bounded on the east and west by longitudinal fault zones, with a downthrow on the eastern zone of more than 2,000 meters (6,560 feet)."

Recent workers in the Cordillera Oriental and the Magdalena Valley have observed the abundance and prominence of overthrust structures. King and Duce (in Schuchert) have clearly described these faults and associated folds which play such an important role in the search for and the occurrence of petroleum (Fig. 8). There are in general two directions of deformation. One direction is, according to Anderson (1927), N. 20°–30° E., more or less parallel with the direction of the Cordillera Oriental. Structures having this trend are characterized by west-dipping fault planes in the eastern part of the range while in the western portion and in the valley, the fault planes dip east (Fig. 8). Where exposed, the planes are usually steep (at Infantas the fault dips 40°–50° E.) but King suggests that they flatten in depth (Schuchert, p. 631). Caster (1940), commenting on King's interpretation of a low-angled thrust at Floresta, reveals that on fossil evidence, the "Tertiary sandy shales" of King are Devonian in age and that no fenster exists at this locality and further the sequence is normal and anticlinal. Duce (in Schuchert) comments correctly on the complex nature of the overthrusts and their associated anticlinal folds. He points out that east of Gamarra the Cordillera Oriental is thrust westward over the Magdalena Valley. His sketch map shows the general distribution of east and west thrusts in Colombia and their general relation to the Venezuelan structures. In the Cesár Valley, Trumpy

(1943, p. 1291) describes a fault of considerable displacement which cuts off the Cretaceous from the Paleozoic east of Manuare in the Perijá Range. In the Rancheria Valley at Cerro Cerrejón, the Eocene is overthrust by the Carboniferous

FIG. 8.—General nature and direction of structural trends in Colombia.

which in turn is overthrust by red-beds unconformably overlain by the Cretaceous Cogollo limestone which forms the top of the mountain (Trumpy, 1943, p. 1295). In these two instances, the thrusting is doubtless toward the west. Cle-

ments (1940) has described the Bogotá fault where the Upper Cretaceous is thrust westward over the Eocene. Butler (1942) refers to the Cambrás fault in the Honda district where a westward overthrust has brought the Upper Cretaceous over the Miocene.

Subordinate to the principal northeast-southwest structural trend is an east-west trend as described by Stutzer (1934d). In the upper part of the Magdalena Valley south of Pandi, the regional strike is N. 80° E., with dips both north and south (Stutzer, 1934h, p. 157). In the valley of Cunday, sandstones and shales have a strike of N. 70° E., and vary in dip from vertical to 35° S. (Stutzer, 1934h, p. 159). In the valley of El Carmen de Apicalá and at Fusagasugá the Guadalupe sandstones strike east and have a steep south dip. Another reading gave S. 60° E., 20° S. (Stutzer, 1934h, p. 161). Stutzer comments on the change in the course of the Magdalena River at Girardot as depending on the structure of the sedimentaries. Here the Guadalupe sandstone strikes N. 70° E., and dips 20° S. (Stutzer, 1934h, p. 163). Southwest of Girardot at Chicoral on the Coello River, asphaltic sandstones strike N. 65° E. and dips 50° S. (Stutzer, 1934h, p. 169). In the middle Magdalena Valley, Stutzer also reports finding these east-west trends. Between Flores and Marsella in Santander, the lower Honda strikes N. 85 W. and dips 32° N. (Stutzer, 1934d, p. 206). The termination of the Magdalena Valley proper at Banco is probably due to an east-west trending "dislocation" according to Stutzer (1943d, p. 204) and Harrison (1929, p. 400). Commenting on these structural trends, Stutzer says that they are not restricted to the valley alone but are also found in the two lateral cordilleras through which they appear to cross. Huntley and Mason (1923) also noted these cross stresses and commented on the nature of the folds as roughly paralleling the north coast of Colombia. Such folds, according to these authors cross the Magdalena River southward from Puerto Berrío and in the region of Banco, and also along the coastal zone.

Structural conditions are not as well known on the western side of the valley as on the eastern side. The idea of a graben structure demands the presence of normal faults both on the east and on the west. Referring to the old crystalline rocks of the Magdalena Valley, Stutzer (1934d, p. 203) says they are not visible on the western side but are transgressed by the Honda formation and are in part separated from it by a pronounced dislocation; where, it is not mentioned. Harrison (1929) refers to faulting on both sides of the valley east and west of Cambao. He further states, "The western side of the Graben is formed by the block-faulted edge of the Central Cordillera. Peneplaned blocks of pre-Cretaceous rocks form the gently tilted plateaux which are so conspicuous in the landscape on the western side of the river from Puerto Wilches to Girardot. The character and relations of some of these blocks have been seen in several sections" (Harrison, p. 407). Anderson (1927) also refers to faulting on the west side of the Magdalena. Duce (in Schuchert, p. 632) shows a thrust fault on his map west of the junction of the Sogamosa and Magdalena rivers. Butler (1942) in his studies on the west side of

the Honda district was unable to find evidence of faulting near Mariquita although he cites a zone of faulting now covered by the Gauli and Mesa formations as one explanation of the westward disappearance of thick Tertiary and Cretaceous sections. Grosse (1926) in his work on "El Terciario Carbonífero de Antioquia" describes numerous faults in the rocks on the western side of the Central Cordilleras. Dickey (1941, p. 1794) on the other hand makes the positive statement that "Contrary to most published work on Colombian geology, there is no evidence of faulting on the west side of the Magdalena valley from Ibaqué to El Banco." Duce (in Schuchert, p. 1560) commenting on Stutzer's statement that the Central and Western Cordillera were dry land during Cretaceous time, cites the lack of conglomeratic facies of the Upper Cretaceous of the Eastern Cordillera and the 10,000 meters of marine Cretaceous measured within a few miles of the Central Cordillera as a possible argument for a gretater extension of the Cretaceous seas than claimed by Stutzer and others. Wheeler (1939, p. 25) reveals that the only known outcrops of the Cretaceous are found near Simití where the lower Palmira rests on the old crystalline rocks. Dickey (1941, p. 1793) commenting on the Girón says it is found on the west side of the valley between Puerto Wilches and Simití where it dips gently eastward and apparently rests on the igneous rocks although the contact was not seen. Rutter (1942) commenting on the facies of the Cretaceous observed on the eastern side of the Central Cordillera points to the lack of clastics and the presence of limestone and shales resting on the basement (Wheeler, 1935, p. 25). Rutter is of the opinion that the Cretaceous extended over the Central Cordillera and was later removed by erosion. The profound faulting observed by Grosse in the western part of the Central Cordillera would hardly disappear before reaching the eastern part of this range. It is still possible that faulting may be present on the western side of the Magdalena Valley, but the nature of the terrain may obscure it. Further, drilling operations now in progress in this area have brought to light evidence of profound subsurface faulting. For the time being, we must agree with Butler that the west side of the valley needs more study.

Cordillera Central and Cordillera Occidental areas.—The region of the central and western Cordilleras is not important as far as the occurrence of petroleum is concerned but the general structural pattern is of interest.

In the valley of the Río Patía, south of the Río Mayo, Stutzer has recorded three structural directions (1934g). The first, N. 25° E., is called the Andian direction and is of secondary importance. The most important direction is N. 40°–50° E., and it is along this trend that important volcanoes are found. Between Buesaco and the Río Mayo, the third direction is referred to as E.–W. (S. 80° W.–N. 40° W.) and is not found north of the Río Mayo (Stutzer, 1934g). Northward in the Patía-Cauca Valley, the principal direction of N. 45° E. changes to N. 25° E. and in the region of Cali it is N. 6°–17° E. In the coal-bearing region of Antioquia the trend has changed to N. 10° W. and in the coastal area

of Barranquilla, the general north-south trend turns toward the west (Stutzer, 1934g, p. 139).

In the Cordillera Central of Antioquia, Grosse (1926) has described anticlinal and synclinal folds and overthrusting, the orogenic pressure coming from the east. According to Stutzer (1934g, p. 139) these structural conditions are rare in the valley of the Ríos Cauca and Patía which is considered as a rift valley.

The results of various workers reveal, therefore, that in general the structural trend in the Cordillera Oriental and the Magdalena Valley is slightly different from that of the Cordilleras Central and Occidental. Concerning the origin of the eastern range and the structures in it and in the Magdalena Valley, the divergence of these structural trends plays an important role.

Theory of De Cizancourt.—De Cizancourt (1933) in explaining the structure of the northern Andes calls attention to two zones, one a geosynclinal zone which includes the Cordillera Oriental and the other a continental area bordering the geosyncline both on the west and east (Fig. 9). In the first zone, folded sedimentary rocks are abundant while in the borderlands, igneous and metamorphic rocks greatly predominate. These borderlands include the Cordilleras Central and Occidental on the west, the Guayana highlands on the east, and the Sierra Nevada de Santa Marta on the north.

The geosynclinal area became a zone of subsidence during the Lower Cretaceous. At the close of the Upper Cretaceous and again during the Middle and Upper Tertiary, the sediments of the geosyncline were folded into tight folds. These folds according to De Cizancourt were due to compression of the thick sediments of the geosyncline between two rigid borderland masses, the Guayana highlands and the Central and Western Cordillera mass. The borderland to the west was affected differently than the zone of folded sediments. Here block faulting producing horsts and grabens is a prominent feature. De Cizancourt points out what has been observed by others that the folds of the geosynclinal zone strike northeast obliquely toward the border of the Cordillera Central and were stopped at this boundary. The branching of the Andes he thinks "is a purely morphologic phenomena and is due to the juxtaposition of folded elements of a geosynclinal origin and of faulted elements belonging to a rigid foreland" (p. 225).

De Böckh, Lees, and Richardson (Gregory, 1929, p. 164) refer to the close of the Cretaceous as a period of strong folding and block faulting. According to these authors, the crystalline rocks in the vicinity of Pamplona are overthrust eastward over the Cretaceous and they refer to these structures as "alpine tectonics." They also think that strong erosion set in at the close of the Laramid revolution. Present evidence proves that this is not the case in many areas of the North Andean geosyncline. Thick sediments were deposited in the areas of subsidence and were folded, but no nappe structures were developed at this time. Strong erosion and volcanic activity is though to have taken place probably at the end of the Pliocene. These authors, therefore, recognize two periods of compression, one producing Alpine structures, the other Germano-type folds.

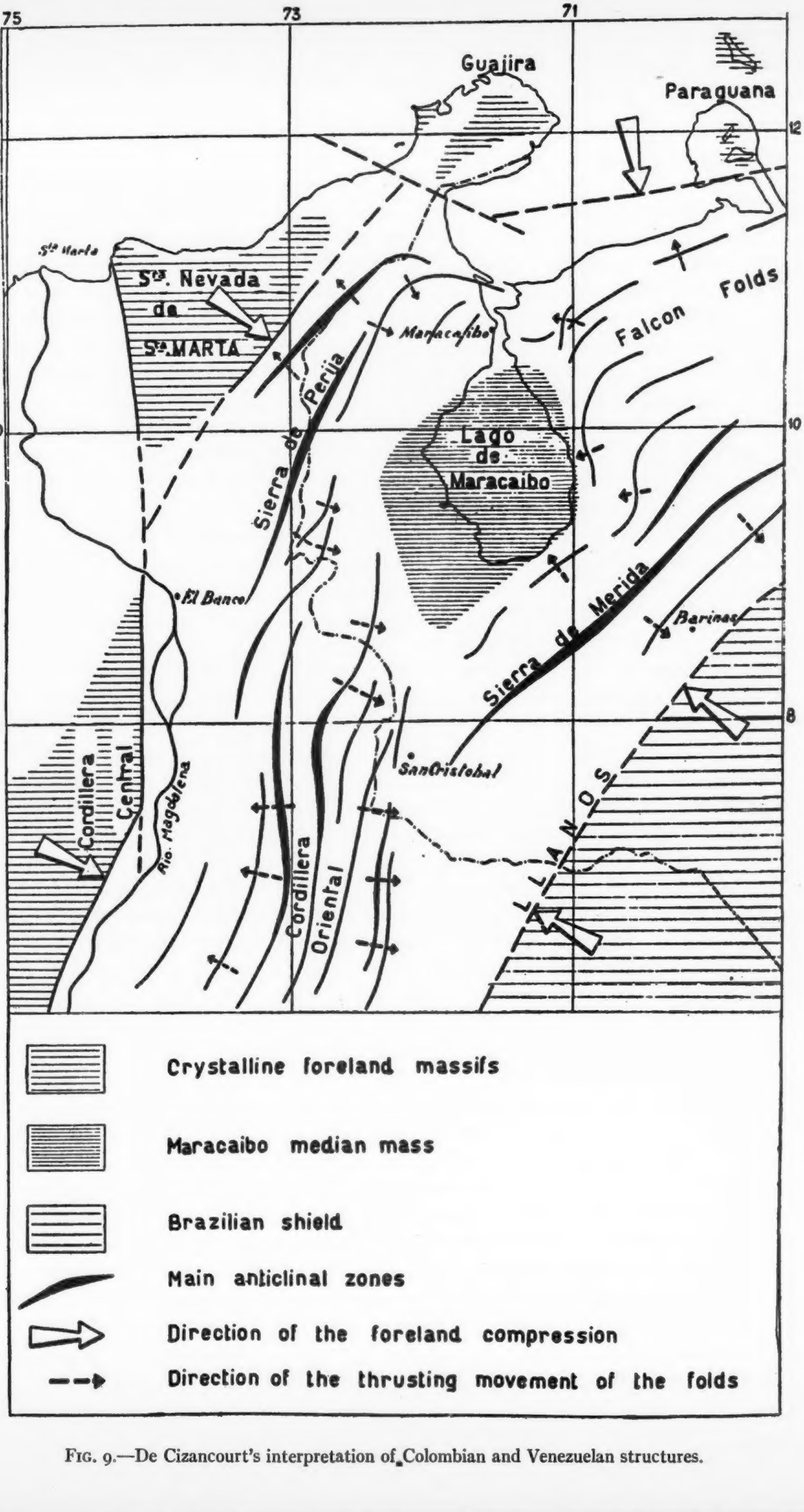


FIG. 9.—De Cizancourt's interpretation of Colombian and Venezuelan structures.

General Stratigraphy

The petroleum geology of Colombia is considered as beginning with the formation of the North Andean geosyncline and the deposition of the Cretaceous formations. Prolonged subsidence during the Cretaceous produced an enormous thickness of strata aggregating nearly 20,000 feet. According to Anderson (1926) the exposure of the Cretaceous in Colombia composes almost the entire Cordillera Oriental, approximately 800 miles long and 40 to 80 miles wide, a large area along the southern boundary of the Sierra Nevada de Santa Marta, and possibly another area along the Cauca Valley.

Hedberg (1940) has outlined in general terms the depositional cycle of the Cretaceous in the North Andean geosyncline. He notes that the Neocomian was characterized by dominantly continental clastics. This was followed by brackish-water and shallow-marine deposition of the Barremian stage which in turn was followed by reef-limestone deposition of the Aptian-Albian. In Cenomanian-Turonian time black limestones were abundantly developed. Senonian sediments are usually shallow-water types with some clastics. The Campanian and Maestrichtian were characterized by shallow-water marine or continental deposits. The non-uniformity of sinking of the Cretaceous basin and the occurrence of local basins caused a variation in the facies of the sediments. Facies correlation is therefore not necessarily time correlation as pointed out by Hedberg (1940). The emergence at the close of the Cretaceous was not uniform and in deeper areas of the geosyncline, deposition continued on into the Eocene.

In discussing Cretaceous sedimentation, use is made of the three-fold division as follows: Lower Cretaceous (Neocomian-Barremian), Middle Cretaceous (Aptian-Turonian), and Upper Cretaceous (Senonian-Danian).

LOWER CRETACEOUS (NEOCOMIAN-BARREMIAN)

A variety of formational names has been given to the Lower Cretaceous of Colombia. From the discussion of the Girón, it is obvious that Hettner's (1892) description of this formation includes in its uppermost part, beds belonging in the Lower Cretaceous. Hettner's (1892) Cocui quartzite consisting of "white to grayish yellow, coarse to medium grained sandstones, interbedded with gray to black beds of clay shales, which are in places carbonaceous" with some limestones at the base (Oppenheim, 1940, p. 1616) and containing plant remains also belongs to the Lower Cretaceous. According to Oppenheim (1940) the thickness is variable, exceeds 2,500 meters (8,200 feet) and contains a Neocomian flora. Dickey (1941, p. 1795) on the other hand points out that Olsson found fossils characteristic of the Middle Cretaceous Tablazo limestone of Santander in the Cocui sandstone at Alto los Cruces, west of Pesca (Boyacá). Since the Cocui thickens toward the east, it is quite likely that it includes both the Lower and Middle Cretaceous.

Anderson (1926) in describing the Lower Cretaceous has doubtless included some beds of this age in his Jiron. This formation consists of red sandstones and variegated sandy shales, non-fossiliferous, and white sandstone locally conglom-

eratic. Anderson's Suarez formation is definitely Cretaceous (Hauterivian and Barremian) and consists of 1,500–2,000 feet of red sandstones, locally very thick; and thin-bedded fossiliferous limestones and marls.

The section described by W. Kehrer (1936) between Bogotá and Villavicencio contains in its lower part a series of gray shales and sandy shales, sandstones, quartzites, and basal conglomerates (Fig. 10). To this series he has erroneously assigned the name Girón. According to Oppenheim (1940), this is the same sequence that occurs in the Río Negro-Cáqueza region to which he has given the name Cáqueza series and is equivalent to the Cocui series. Hubach (W. Kehrer, 1936, p. 311) also described the Bogotá-Villavicencio section of sandstones, quartzites, shales, and conglomerates, giving names to the lithologic units and also erroneously classifying them as Girón.

Hubach (1931) described a section in the Apulo-San Antonio-Viotá region, southwest of Bogotá and lying on the western flank of the Cordillera Oriental. Here the Lower Cretaceous (Barremian) contains at the base calcareous sandstones overlain by coral limestone with shale and in turn is overlain by quartzitic fossiliferous sandstones.

As pointed out by Hedberg (1940, p. 210) the Lower Cretaceous in the vicinity of the Nudo de Santander is variable in thickness and is characterized by coarse clastics. Land conditions probably existed nearby and the sea probably did not cover the area until late Barremian or Aptian time (Hedberg, 1940, p. 210). East of the Nudo de Santander, the Lower Cretaceous is included in the Uribante formation which according to Hedberg varies from 0 to 1,000 meters (0 to 3,280 feet) in thickness. The Uribante beds are composed of "light greenish-gray and brown sandstones which are locally conglomeratic but includes dark shales and some limestones." Red shales and siltstones are also included within the Uribante formation. Farther north, according to Hedberg, the Lower Cretaceous is represented by the Río Negro conglomerate consisting predominantly of light-colored feldspathic sandstones and quartz conglomerate, locally at least 3,000 meters (9,840 feet).

West and southwest of the Nudo de Santander, the Lower Cretaceous is represented by limestone, shales, and sandstones (Fig. 11). They locally are called the Rosa Blanca limestone at the base, overlain by the Paja or Pay shales which may be sandy or calcareous. The Rosa Blanca limestone and Paja shales form the basal part of Wheeler's Palmira series (Wheeler, 1935).

In 1892 Hettner introduced the term Villeta for the highly fossiliferous Cretaceous dark to black shales with interbedded quartzites, red and white sandstones, and blue, black, and white sandstones exposed near Villeta about 40 miles northwest of Bogotá. The thickness of this group is several thousand meters (Schuchert, 1935, p. 668). The age of the Villeta may range as high as the Cenomanian and Turonian stages of the Cretaceous, but Hettner's original limits, according to W. Kehrer (1939), ranged from upper Hauterivian to upper Albian.

In the southern part of the Central and Eastern Cordilleras, fossiliferous

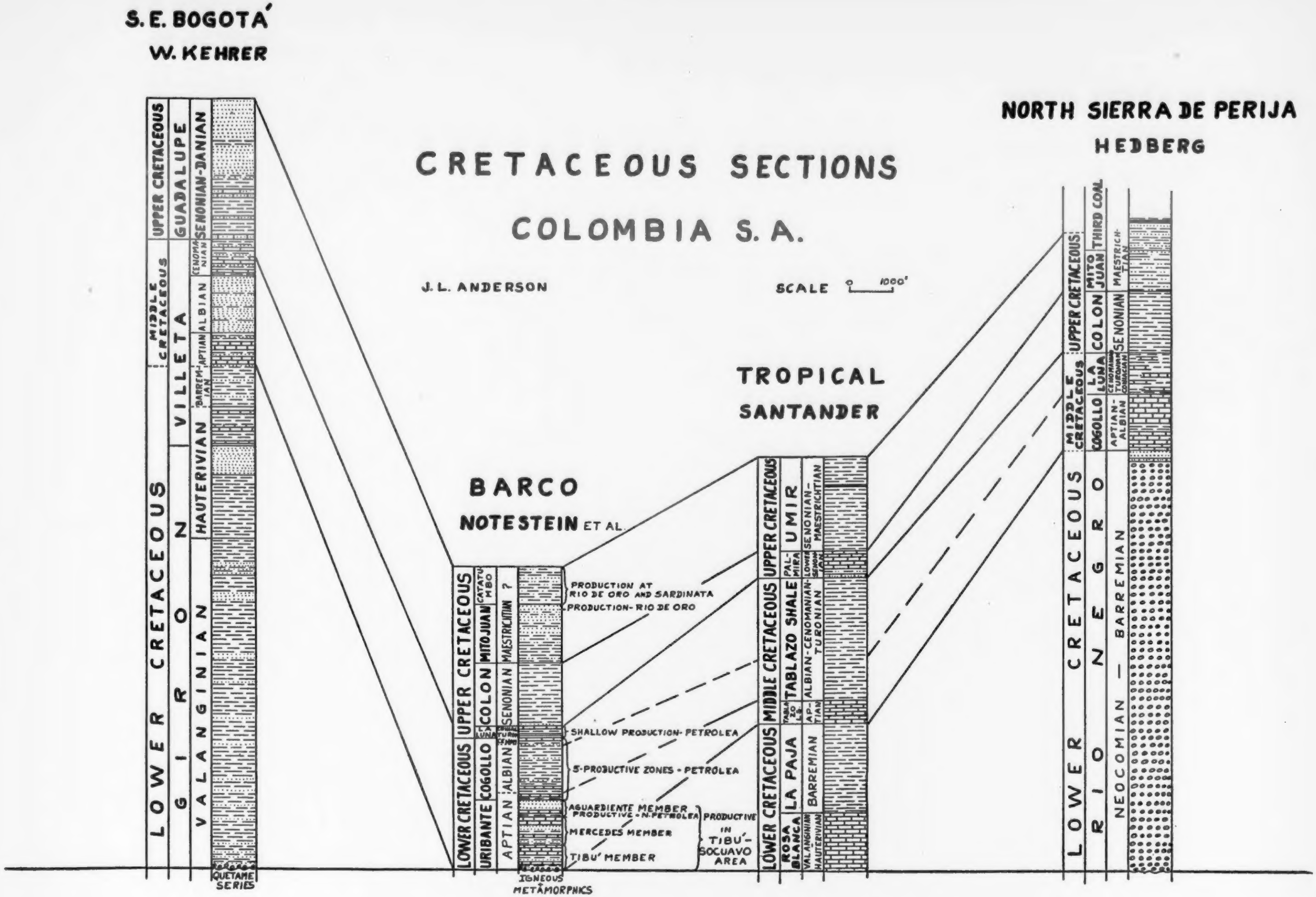


FIG. 10.—Cretaceous columnar sections, Colombia.

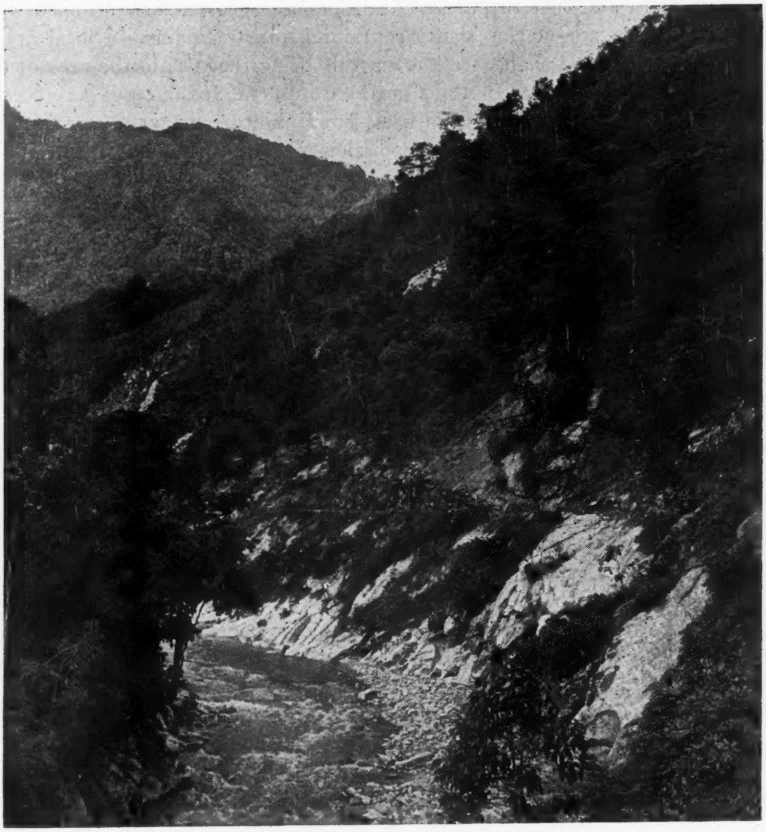


FIG. 11.—West-dipping Lower Cretaceous beds, Lebrija River gorge, Pto. Wilches-Bucaramanga R.R.

limestones have been classified as Villeta (Barremian) by W. Kehrer (1939) Grosse (1935b) has described a Cretaceous porphyrite formation in the extreme southwest part of Colombia which contains intercalated siliceous shales and sandy shales. Poorly preserved foraminifera are contained in the shales.

In the Cordillera Central at Loma Hermosa in the department of Antioquia, Scheibe (1933b) found ammonites in hard black slaty shales. These shales and calcareous beds are intercalated in diabase or melaphyre and were tentatively referred to the "jura-triassic." Grosse (1926) also collected poorly preserved bivalves and ammonites in bituminous, loamy shale at Loma Hermosa which Steinmann says indicate a Barremian age for these beds (Grosse, 1926, p. 54).

Generally, the Lower Cretaceous is characterized by coarse clastic sediments

FIG. 10.—Cretaceous columnar sections, Colombia.

in the southern and eastern parts of the Colombia geosyncline. Mingled with these clastics are non-marine shales containing plant remains. In local areas, marine limestones and shales are known, this being the case in the area of the middle Magdalena Valley. In the Central Cordillera, fossiliferous Cretaceous black shales are intercalated within basic flows, indicating that submarine volcanic activity occurred during the deposition of Cretaceous beds and that the area represented a border zone of the geosyncline.

MIDDLE CRETACEOUS (APTIAN-TURONIAN)

The middle Cretaceous of Colombia exhibits an interesting change in facies from south to north and from east to west (Fig. 10). Hedberg (1931 and 1940) has described two formations of this age west of Maracaibo, Venezuela, in the Sierra de Perijá Range. The lower of these is a 400-meter dense gray, hard, massive, and rather coarsely crystalline, highly fossiliferous, shallow-water limestone containing some gray shale, and sandy and glauconitic beds. The name Cogollo limestone has been given to this formation. Overlying the Cogollo limestone is a "dark gray or black carboniferous, bituminous, shaly limestone or calcareous shale which is made up of varying proportions of calcium carbonate, clay matter, and organic matter" (Hedberg, 1940, p. 212). The name of this formation is the La Luna limestone. It is rich in foraminifera, fish scales and remains, and local development of mollusks. These two middle Cretaceous limestones are thought to be present in the northeastern part of Colombia.

Hedberg (1940, p. 213) points out the change in facies in Norte de Santander where the La Luna has decreased in thickness to 50–75 meters (164–246 feet) and the upper part is black chert. Below the typical La Luna is a section 800 meters (2,624 feet) consisting of barren shale and interbedded limestone, glauconitic sandstone and shale, and Cogollo-type limestone and black shale.

In Santander, the Middle Cretaceous is represented by a hard, gray limestone and chert formation known as the Palmira limestone which is underlain by hard black poorly fossiliferous shale known as the upper Tablazo shale. This in turn is underlain by the same type of shales which are highly fossiliferous. Underlying these shales is hard, dark gray to black richly fossiliferous limestone known locally as the Tablazo limestone (Fig. 12).

Etherington (1944) has reported the occurrence of the *Oxytropidoceras* ammonite zone in the middle Albian. The zone is said to extend over an area of 120 miles by 40 miles in the upper Magdalena Valley on both sides of the basin.

Passing southward into Boyacá and Cundinamarca, the lower part of the Middle Cretaceous becomes sandier. The Middle Cretaceous of Hubach's (1931) section west of Bogotá on the west flank of the Cordillera Oriental contains thin calcareous sandstones in fossiliferous pyritic black shales overlain by abundantly fossiliferous pyritic black shales with siliceous shales near the top. This series is known as the Villeta formation.

W. Kehrer's (1936) and Hubach's sections southeast of Bogotá reveal considerable sandstone and quartzite in both the lower and upper portions of the Vil-

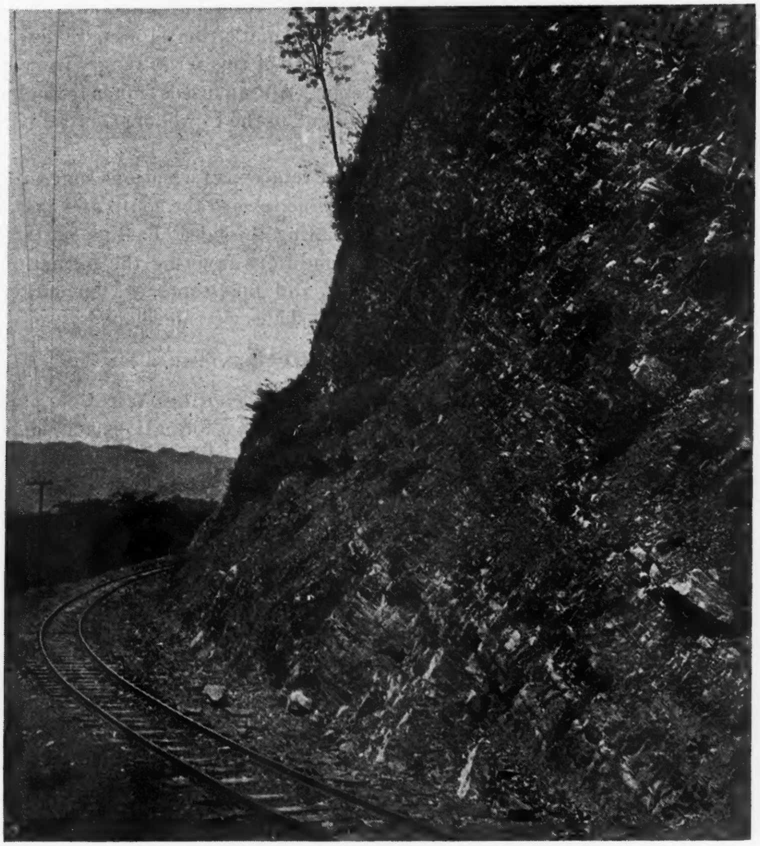


FIG. 12.—West-dipping Middle Cretaceous limestones and shales, Pto. Wilches-Bucaramanga R.R.

leta. Black bituminous limestones and shales, highly fossiliferous, are abundant.

In northwestern Putamayo, Kehrer (1939) has described shales, sandstones, and limestones of the Villeta which are in turn overlain by a porphyrite formation, referred to the Guadalupe or Upper Cretaceous. Grosse (in Kehrer, 1939) has described in the department of Huila in the southern part of the Cordillera Central, Lower Cretaceous beds consisting of conglomerates, red sandstones, and gray shales overlain by brown porphyrite tuff with the 200-meter Arabuco quartzite sandstone on top. The Villeta follows above this and consists of black bituminous shales and limestones and some gray sandstones, ranging in age from Barremian to lower Senonian. On the upper Río Caquetá in the southern part of the Cordillera Oriental, porphyrite and white sandstone equivalent to the Arabuco

sandstone are overlain by black shales with some red-green sandstone and dark limestone. These are in turn overlain by black marls, limestones, shales, and siliceous shales with tuff beds at the top. The age of this series ranges from Barremian to Turonian. Gerth (1935, p. 358) reports Aptian fossils from a ferruginous calcareous sandstone at Ebéjico on the west flank of the Cordillera Central northwest of Medellín in Antioquia.

The foregoing descriptions of the Middle Cretaceous formations suggest that shallow-water conditions existed during this time toward the south and east, the presence of coarse clastic material substantiating this idea. Passing northward and westward progressively deeper-water conditions favoring the formation of shales, interbedded fine sandstones, cherts, and limestones are encountered. Farther northward marine type limestones and shales were developed.

UPPER CRETACEOUS (SENONIAN-DANIAN)

The Upper Cretaceous of western Venezuela and northeastern Colombia in the Sierra de Perijá Range has been divided into three formations according to Hedberg (1940). At the base are the Colón shales consisting of a thin sandy glauconitic and phosphatic zone overlain by 100 to 450 meters (328 to 1,476 feet) of gray fissile shale with benthonic Foraminifera. Overlying the Colón shales are the greenish gray sandy shales "carrying a scant brackish water to marine foraminiferal fauna" and varying from 100 to 300 meters (328 to 984 feet) in thickness. These constitute the Mito Juan formation. At the top of this formation is, according to Hedberg, "a unit of thin fine-grained sandstones, thin ironstones, glauconitic limestones, and greenish-gray shales known as the Río de Oro formation." Ammonites identified as *Sphenodiscus* and *Coahuilites* indicate a Maestrichtian age for these beds (Fig. 10).

In the middle Magdalena Valley area, the Upper Cretaceous is represented by the black, clay-ironstone shales, sandstones, and coal beds, of the Umir formation. This formation is about 900 meters (2,952 feet) thick and is equivalent to the Colón, Mito Juan, and Río de Oro formations. The Umir carries both an Upper Cretaceous foraminiferal and ammonite fauna (Fig. 10).

The Upper Cretaceous of the Cordillera Oriental in the area between Bucaramanga and Bogotá is included in what is known as the Guadalupe formation. This formation is about 4,000 feet thick and consists of light-colored sandstones, sandy shales, chert, and siliceous shales. It appears to be the equivalent of the Umir and the uppermost portion of the Villeta. Coal beds are known in the upper part. The age ranges from Cenomanian to high in the Senonian. Fossils are not abundant but fish remains, *Inoceramus*, and the pelecypod *Roudairea* are reported by Gerth (1935, p. 357).

The Guadalupe formation in Hubach's section southeast of Bogotá contains a lower member which is a laminated shale, in part calcareous and containing fish remains. Overlying this is an upper member which is a sandstone containing *Roudairea*. The thickness according to Hubach ranges between 700–1,000 meters (2,296–3,280 feet) and the age from the Turonian through Senonian (Fig. 10).

The Upper Cretaceous of the southeastern part of the Cordilleras Oriental and Central is characterized by an abundance of basic extrusions and tuffs. In the upper part of the Río Caquetá, Grosse (1935a) reports tuffaceous sand, siliceous shales with foraminifera, together with melaphyre and porphyrite in the Upper Cretaceous. The Cretaceous of the Western and Coastal Cordilleras is characterized by basic intrusive and extrusive rocks. On the other hand, Hubach (1930, p. 67) describes a section about 1,000 meters thick containing alternating thick and thin gray slates and quartzites. Ammonite remains were encountered in these beds near the headwaters of the Río Napipí on the eastern flank of the Coast Ranges. Petrographically, Hubach thinks they resemble the Upper Cretaceous of the Cordillera Oriental. Olsson (1940, p. 252) on the other hand thinks this section should be studied in more detail before a Cretaceous age is assigned to it.

The Mesozoic came to a close in the North Andean geosyncline, not by a pronounced orogeny but by broad epeirogenic movements which caused a slow withdrawal of the Cretaceous sea. Sedimentation, characterized by coarse clastics and volcanic material in the southern part of Colombia and shallow water and swampy conditions farther north in the central Cordillera Oriental, in most areas continued uninterrupted well into the Tertiary. There are local areas where an angular unconformity exists between the Cretaceous and Eocene as at La Cira on the De Mares Concession of the Tropical Oil Company in Santander. Hubach characterizes this orogenic period as producing local discordance in the Cordillera Oriental, the discordance becoming apparently strong toward the west. In the Central Cordilleras, Grosse (1926) reports the presence of dioritic and granitic intrusions as marking the beginning of the Cenozoic. Rutten (Hedberg, 1940) also reports dioritic and granodioritic intrusions in the Paleocene of the islands off the northern coast of South America.

TERTIARY

The entire Tertiary section of Colombia shows a marked change in facies from north to south. In the Magdalena Valley, this facies change is especially marked. The formation of the so-called Magdalena graben which had its beginning at the close of the Cretaceous and its culmination in the profound orogeny of the Pliocene, is largely responsible for the type of sediments laid down. Marine sediments are in general limited to that portion of the country north of El Banco. The sediments of the Magdalena Valley and northern Colombia therefore represent two types of depositional environment, namely, marine in the north and non-marine or estuarine and lacustrine in the middle and southern portions.

Tertiary sediments are also known in the valley of the Río Cauca and have been described in detail by Grosse (1926). They consist of abundant coal deposits in strata composed of conglomerates, sandstones and shales, containing freshwater fossils. Late Tertiary rocks of this region are mostly volcanic and consist of andesites in the form of laccoliths, sills, and dikes with sills and dikes of basalt. The Tertiary deposits of the middle and upper Cauca Valley are doubtless of no

value as far as the occurrence of petroleum is concerned. The sediments of the Cauca Valley merged into the marine Tertiary of the northern part of the country.

Sedimentary rocks of Tertiary age are also known from the valley of the Río Atrato between the Cordillera Occidental and the Serranía de Baudó but have not been systematically studied. They consist of conglomerates, sandstones, and fossiliferous and carbonaceous shales.

In the extreme southwestern part of Colombia in the department of Huila, E. Grosse (1935a) has described conglomerates, sandstones, and fossiliferous shales belonging to the Lower and Middle Tertiary which are overlain by Upper Tertiary andesitic tuffs and agglomerates, sands, and shales.

From a petroleum standpoint, the Tertiary deposits of the Magdalena Valley and those of the north coast of Colombia are the most important. They extend along the north coast of Colombia from the Gulf of Urabá eastward to the Sierra Nevada de Santa Marta and beyond and are also found in most of the large valleys of the low country, such as the Río Magdalena, Río Cauca, Río Cesár, Río San Jorge, and Río Sinú. Tertiary sediments are also known to extend far south into the upper part of the Magdalena Valley and in the high plateaus of the Cordillera Oriental at elevations up to about 9,000 feet. They are also known on the high eastern slopes of the Cordillera Oriental in the llanos region. All periods of the Tertiary from the Eocene to the Pliocene are represented in the Magdalena Valley and in the northern portion of the country. Because of the economic importance of the Tertiary, its sediments are considered in more detail.

LOWER MAGDALENA VALLEY AND NORTHERN COASTAL AREA

Eocene.—According to Anderson (1928) the Eocene deposits of the lower Magdalena Valley and along the north coast of Colombia, with the exception of certain coal-bearing members, are almost entirely marine. The beds crop out around San Andrés, east of the Sinú Valley and according to Anderson appear to underlie a large portion of the San Jorge Valley. In the hills east and west of the Sinú Valley, Eocene cherts, limestones, and hard sandstones can be observed. Anderson has measured a marine Eocene section near El Carmen in northern Bolívar, the thickness of which is 4,500 feet and the lithologic character is as follows (Fig. 13).

Bed	*Description*	*Thickness (Feet)*
G	Clay shale, sandy clay shale, with white siliceous shale, probably organic (not known to be the top)	1,000
F	Concretionary sandy shale, sandstone, etc., with molluscan fossils, foraminifera, petrified wood, etc.	600
E	Yellow thin bedded sandstone, weathering red	400
D	Whitish shale, with lenses and thin beds of limestone, sandstone, etc. (Tofeme group, with thin beds of lignite and carbonaceous matter near bottom)	800
C	Earthy or hard, thin bedded, siliceous shale, marly shale with limestone containing molluscan fossils	800
B	Yellow concretionary sandstone	500
A	Heavy beds of sandy conglomerate (near Cansona)	400
	Total	4,500

The age of this section is middle and upper Eocene (Anderson in Schuchert, p. 662) and is equivalent to the Arjona series of the Cartagena district. Royo y Gomez (1942e) has studied numerous Tertiary fossils which were collected in the northern part of Colombia and whose age ranges from possibly upper Oligocene to lower Pliocene.

Beck (1921) measured a section near Sincelejo in the eastern part of the Sinú Valley. On the basis of Anderson's correlation (1928, p. 11) two formations are placed in the upper and middle Eocene, a basal limestone 200 feet thick known as the Palmito limestone overlain by the Tofeme formation (1,500+ feet) consisting of red shales and light gray sands.

A. Wehrenfels (1926) describes a Tertiary section near Toluviejo approximately 35 miles northwest of El Carmen in Bolívar. The basal Eocene known as the Arroyo Seco formation varies from 65 to 130 feet in thickness and consists of "loose diorite pebbles of a diameter of 1 meter and more which changes in lateral extension to a coarse grained and poorly consolidated sandstone." The Arroyo Seco formation overlies black shales and limestones which are probably of Cretaceous age. The Arroyo Seco is doubtless equivalent to Anderson's bed "A" which is decidedly thicker. Overlying this basal conglomerate, Wehrenfels describes a limestone-sandstone series known as the Toluviejo series whose thickness is about 1,312 feet. Foraminifera are present in the limestone and according to Wehrenfels, suggest an upper Eocene age for this series. He correlates it with Beck's Palmito limestone but Anderson places it much higher in the section and equivalent to his clay shales, sandy shales, and siliceous shales of bed "G."

Washburne and White's (1923) section in the Cesár Valley contains sandstone and conglomerate 800 to 1,000 feet in thickness and consisting of well rounded pebbles of chert and igneous rocks. This part of the section they refer to the Lower Tertiary, unconformably overlying Cretaceous black shales.

Oligocene.—There is little published information on the Oligocene of the northern part of Colombia. According to Olsson (in Schuchert, p. 660) the lower Oligocene is missing and the middle Oligocene consists of very thick massive sandstones, conglomerates and some coal beds. Limestones with large *lepidocyclinae* are found. The upper Oligocene according to Olsson is represented by highly fossiliferous shales equivalent to the Tapaliza shales of the Darien region. Anderson calls the Oligocene of the lower Magdalena Valley the San Juan group (Anderson, 1927, p. 595) whose thickness may be as much as 5,000 feet (Fig. 13). Anderson also used the name Poso series to describe sandstones, conglomerates, sandy shales, and shales whose thickness ranges from 3,400 to 6,000 feet and which lie unconformably on the Eocene and go unbroken into the Miocene.

In the Sinú Valley, fossils from the Bombo shales of Beck which he called Miocene were determined by Vaughan as of Oligocene age (Anderson, 1927, p. 611). The shales are over 500 feet thick and it is possible that some of Beck's overlying section is also Oligocene. Schuchert refers to the Monitos shales of Oligocene age as having a thickness ranging from 400 to 1,800 feet. The Poso

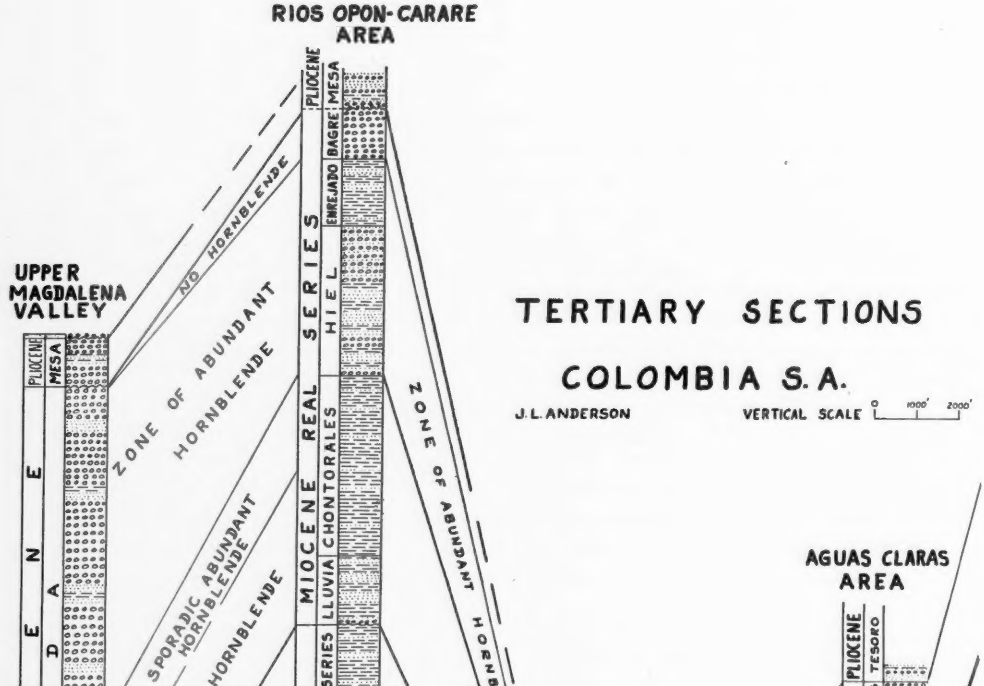


FIG. 13.—Tertiary columnar sections, Colombia. South end.

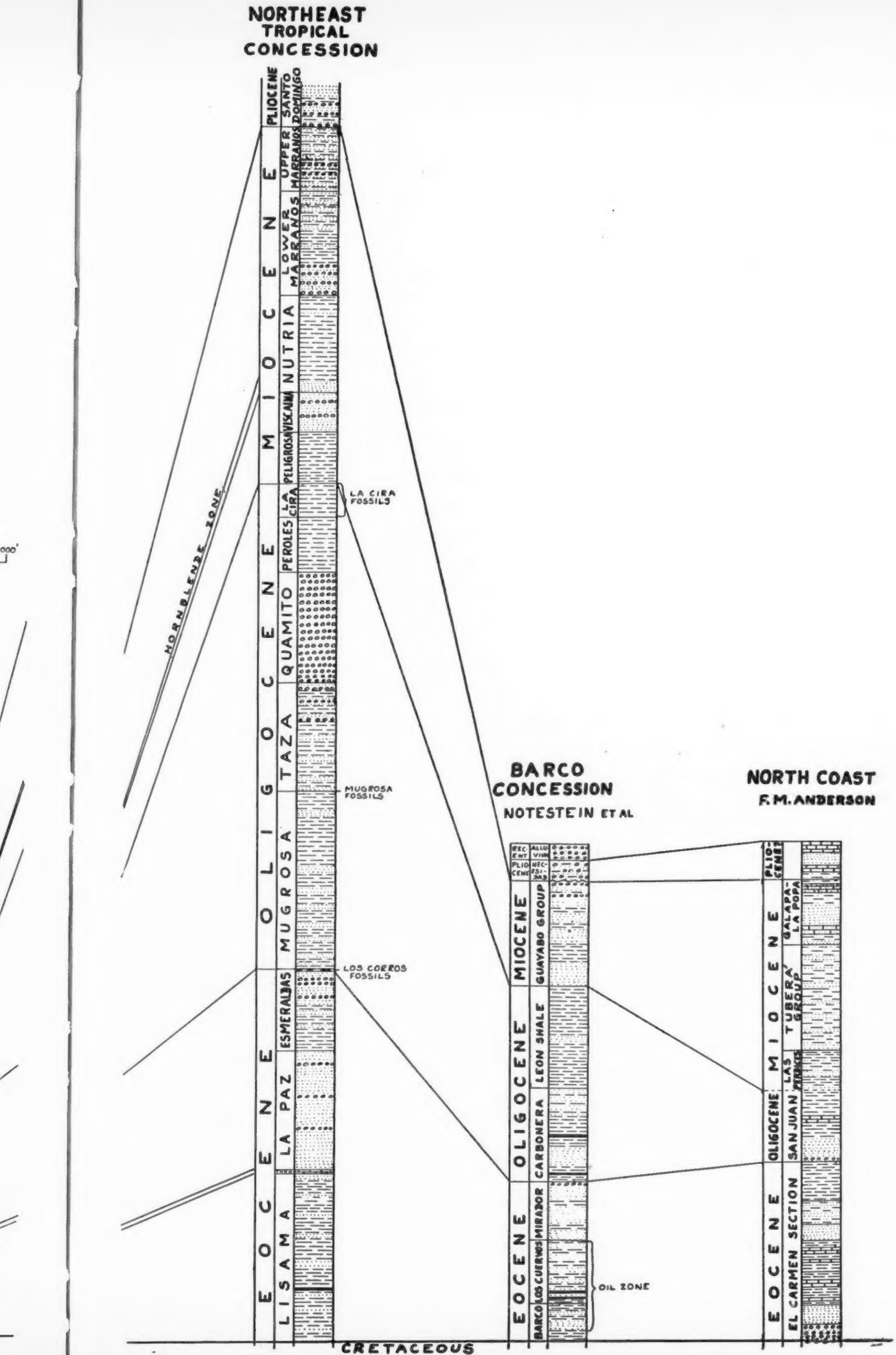


FIG. 13.—Tertiary columnar sections, Colombia. North end.

series of Anderson lies unconformably over the Eocene at the type locality at Cerro de San Sebastian and in the Cerro de Cispata near Lorica (Anderson, 1929, p. 85).

Miocene.—The Miocene of northern Colombia is very extensively developed, reaching from the Gulf of Urabá eastward along the coast to the Sierra Nevada de Santa Marta. It occurs again in the vicinity of the Río Hacha and according to Anderson (1929) may extend southward into the valley of the Río Cesar, thence to its junction with the Río Magdalena. From this point, they are known westward in the valley of the Río San Jorge, in the valley of the Río Sinu and in the valley of the Río Atrato. According to Anderson, there is evidence of local unconformities between the Miocene and the underlying Poso series (Anderson, 1929). Three groups compose the Miocene of this region (Fig. 13).

Las Perdices group is named from strata cropping out near Las Perdices approximatley 15 miles west of Barranquilla. Sediments of this group consist of fossiliferous clay shales, sandy shales, and hard chert and possibly separated from the overlying Tuberá group sediments by a disconformity. The thickness as given by Anderson is 1,000 feet or more but Olsson thinks that the lower part of this group may be upper Oligocene (Renz, 1940, p. 550).

The Tuberá group overlies the sediments of the Las Perdices group and have been described in detail by Anderson. The thickness is not less than 2,650 feet and the sediments are "incoherent sandstones and sandy shales." Three fossil horizons, zones M-N, P, and R of Anderson, are known. The group has a very wide extent in the northern part of Colombia and is probably equivalent to Beck's Huertas limestone and possibly part of his San Antonio sandstone. Royo y Gomez (1942 e) has studied numerous fossils from northern Colombia and belonging to the Tuberá group. On the basis of its fossil content the Tuberá group is correlated with the middle Miocene Gatun of the Canal Zone.

The Usiacuri formation is probably equivalent to the Galapa-La Popa group of Anderson and overlies the Tuberá group. The formation consists of calcareous sandstone, incoherent sandy shales and clays. The thickness according to Anderson is in excess of 1,650 feet. Anderson (1929, p. 99) points out that his Galapa-La Popa group is of limited extent and suggests the presence of an unconformity between it and the underlying Tuberá group. Wehrenfel's Cerrito formation and Savana sandstone are referred to the Miocene.

Pliocene.—Deposits tentatively placed in the Pliocene were noted by Anderson along the railroad between Puerto Colombia and Salgar and in the vicinity of Barranquilla. They consist of coral limestone, sandstone, and sandy clay shales, aggregating 910 feet in thickness (Anderson, 1929, p. 100). The limestones are very fossiliferous, containing corals, mollusks, and gastropods and are also recognized at the top of La Popa hill at Cartagena. These so-called Pliocene sediments are thought to be unconformable above the Miocene.

Pleistocene.—Marine terraces and raised beaches are abundant along the northern coast of Colombia where they contain corals and recent marine shells.

According to Anderson (1927) they are not commonly found above an elevation of 50–60 feet. Along the lower parts of the Magdalena River, Pleistocene alluvium in the form of horizontally stratified silts, sands, gravels, and clays are known.

MIDDLE MAGDALENA VALLEY

Eocene.—The Tertiary geology of the middle Magdalena has been excellently described by Wheeler (1935) and his general outline is followed here. The middle Magdalena Valley extends from El Banco at about 9° to Honda at approximately 5° N. Lat.

Lisama formation.—The Upper Cretaceous well bedded, fossiliferous and coal-bearing, black shales of the Umir formation are followed by what appears to be a transition series consisting of mottled shales and thin carbonaceous, micaceous shales with alternating fine to very fine sands up to 25–30 feet thick (Fig. 13). Some beds of coal are known in this series but their development is not as extreme as those of the Umir. This series is known both as the Lisama formation and the Orocué formation. Wheeler considered the Lisama as probably middle Eocene in age due doubtless because the Umir was assigned to the Eocene. Later evidence based both on megafauna and microfauna has placed the Umir in the Upper Cretaceous. The heavy-mineral content of the sands in the upper part of the fossiliferous Umir north of the Sogamosa River is identical with that of the basal Lisama. The Lisama is therefore considered to be in part lower Eocene and in part Upper Cretaceous, as advocated by Hedberg (1937).

Toro formation.—A period of erosion set in after the deposition of the Lisama which removed much and in some places all of this formation. As pointed out by Wheeler, at Peña Cruces, near the mouth of the Quebrada Putana on the Sogamoso River, 2,500–3,500 feet of Lisama beds are exposed. "Fifteen miles south the formation is 700 feet thick, and about 8 miles farther south, it is entirely missing." From 6 to 8 miles still farther south, the Lisama is "alternately present, in thicknesses up to a few hundred feet, and completely absent." In the La Cira oil field one well penetrated about 60 feet of hard, jointed, highly mottled shales transversed by veins of calcite and medium to coarse, argillaceous sands with flesh-color chert grains immediately overlying the Cretaceous black shales. This section represents the Lisama formation. North of the Sogamoso River at Aguas Claras, the Lisama is about 2,000 feet and on the Río Lebrija, it has thickened to 4,100 feet.

The Toro formation or "altered shale" as it is locally termed, is well developed between the Sogamoso and Opon rivers, where depending on the magnitude of the unconformity, it rests on the Lisama or older formations. As revealed by Wheeler, it is not known south of the Opon River and becomes sandy, soon disappearing north of the Sogamoso River. The Toro is ordinarily no more than 100 feet thick and is hard, light bluish to pearl gray, massive shale, in places jointed, and here and there thin-bedded. The thin-bedded variety is commonly pale gray to white and contains siderite spherules. The more massive variety

possesses much ferrous carbonate and is in many places a clay ironstone.

The variable lithologic character indicates that the Toro formation was formed in a reducing environment which favored the production of ferrous iron. The relatively limited extent of the Toro suggests a lagoonal or shallow-water environment where the carbon dioxide content was sufficiently high, favoring the precipitation of ferrous carbonate. This indicates a limited submergence of the Eocene basin after the erosion of the Lisama formation.

The age of the Toro, as suggested by Wheeler is probably upper Eocene, if the unconformity at the top of the Lisama marks the close of the middle Eocene.

Chorro series.—The beds included between the top of the Toro formation and the top of the Los Corros fossil horizon marking the top of the Eocene section have been called the Chorro series. At the La Cira oil field approximately 5 miles east of the Magdalena River they have been cored in wells. On the Infantas structure they have also been cored and are found on the outcrop east of a north-south trending fault. In these two fields, the Chorro series consists essentially of two units, a lower 550-foot section consisting of hard, mottled red and brown bluish green to gray shales with a minor amount of very fine-grained silty sand known as the D zone and an upper unit known as the C zone, consisting of predominately medium-grained, partially consolidated sand containing coarse and gravelly variations and intercalated mottled tough shales. The C zone is the most important oil-producing unit in the central part of Colombia.

The Chorro series is found in the outcrop only on the east side of the Magdalena River. The top of the series in both the Infantas and La Cira fields is marked by a thin zone of black carbonaceous shales, in places carrying a small amount of fine glauconitic sand. The Los Corros fossils have not been found in either field but where they are known, they occur in beds lithologically similar.

The thickness of the Chorro series is variable and increases both south and east from Infantas (Fig. 13). With this increase in thickness there is also a lithologic change. Approximately 12 miles south of Infantas the section is predominately shale with sandy shales and fine-grained sandstones and is about 1,300 feet thick. On the Sogamoso River near Quebrada Putana, the Chorro series is approximately 3,000 feet and at Santa Marta, 8 miles farther up stream 6,500 feet have been reported, but as Wheeler points out, this is possibly an exaggerated thickness. On the Sogamoso River the lower part of the Chorro series is known as the La Paz sandstone, a massive, coarse-grained crossed-bed mountain-forming sandstone. North of the Sogamoso River this unit is known as the Angosturas formation. Overlying the La Paz or Angosturas is the Esmeraldas formation, consisting of dull mottled shales and interbedded fine-grained sandstones. North of the Sogamoso River, the Esmeraldas consists of a basal shale unit overlain by micaceous cherty, fine to very coarse sandstones. The Angosturas and Esmeraldas in this area measure about 3,400 feet.

Based on faunal evidence Olsson suggests that the Chorro series is late upper Eocene in age (Wheeler, 1935, p. 31).

Oligocene.—The Oligocene of this area is represented by two series each containing shales and sandstones (Fig. 13). The Oligocene begins at the top of the Los Corros fossil horizon and continues upward to the top of the La Cira fossil interval. Between these two fossil horizons is another known as the Mugrosa fossil zone. The Oligocene section shows a thickening both south and east. The interval between the Los Corros and Mugrosa fossil zones at the La Cira oil field is about 1,200 feet, and increases away from the La Cira field to 4,500 feet. The interval between the Mugrosa and La Cira fossil zones varies from 2,600 feet at La Cira to 6,900 feet in the foothills at the east.

Overlying the Los Corros zone at the La Cira and Infantas oil fields is a section known as the Mugrosa series, the lower 700 feet of which is called the lower B zone and which contains dull blue-gray to brown mottled clays with thin very fine-grained sands here and there. The upper B zone consists of fine to medium to coarse, in places pebbly sandstones and thin mottled shales. The Mugrosa series, as pointed out by Wheeler, shows an increase in the sand content of the lower B zone from west to east whereas in the upper B zone, shales become more abundant.

The lithologic character of the Mugrosa fossil zone is very interesting. Ordinarily the fossils occur in brick-red shales at La Cira where calcified molds and casts of small gastropods are abundant. At Infantas, the same fossils are found well preserved in black shales which in places show small amounts of glauconite. The thickness of the Mugrosa fossil zone varies from a few inches to about 25 feet. There is apparently a slight unconformity at this point in the section. The age of the Mugrosa fossils is considered to be middle Oligocene according to Pilsbury and Olsson (1935).

Overlying the Mugrosa series is another succession of mottled bright-red shales and coarse sandstones known as the Colorado series. In the area of the La Cira-Infantas fields this series is approximately 3,300 feet thick but increases in thickness to 7,700 feet about 19 miles northeast. The basal 500 feet of this series consists of shales and streaks of hard pyritic calcareous, fine-grained sands known as the lower A zone. These are followed by 700 feet of medium to coarse, hard pyritic and calcareous sandstones with some mottled shale known as the middle A zone. The upper A zone consists of red and gray mottled shales and some thin sandstones, the unit being about 550 feet thick. The Guamito formation, known as the Pebbly Sand horizon in the La Cira field, and having a thickness of 350 feet, overlies the upper A zone and is in turn overlain by 300 feet of bright mottled shales to the base of the La Cira fossil zone. The Guamito formation increases in thickness to 2,800 feet and changes in lithologic character to conglomerate about 15 miles eastward.

The La Cira fossil zone or formation is a 350-foot succession of dull gray waxy well bedded shales and interbedded yellow-green, medium-grained sandstones. Fresh- and brackish-water mollusks and fossil leaves occur in several beds. The fossils are known, according to Wheeler, from the Sogamoso River south to the

Opon River. Butler (1942) reports this fossil zone in thin lignitic beds along the Cundinamarca Railroad. It was absent north of the Sogamoso River at Aguas Claras. The age of the fossils is considered to be upper Oligocene.

Miocene.—There is evidence of an unconformity not far above the La Cira formation. A break in sedimentation with the advent of an entirely new suite of minerals, and the absence of the La Cira fossil zone in certain localities, supports this idea.

The Miocene of the middle Magdalena Valley is called the Real series and has been divided into at least 11 different formations by the geologists of the Tropical Oil Company. The series consists of poorly sorted coarse to conglomeratic sandstones and red and brown mottled shales. As Wheeler (1935) has pointed out, in the region of the Río Opon, the La Cira fossils are missing and the basal Real consists of chert cobbles and boulders up to 6 inches in diameter. In the La Cira oil field the basal Real consists of red-splotched shale resting on the La Cira fossil zone.

The thickness of the Real series is extremely variable (Fig. 13). In the La Cira oil field area the 1,400-foot section consists of red- and brown-splotched gray shales and coarse sands known locally as the Peligrosa shales and the Viscaina sandstone. Overlying the sandstones of the Viscaina is the Nutria formation consisting of 300 feet of brownish green shales and fine-grained sandstones. The sands of the Nutria contain a large amount of hornblende and magnetite.

In the area of the Sogamoso and Oponcito rivers, the Real series consists of more than 9,400 feet of gray shale with red and brown mottling, coarse, white, crossed sandstones, green-gray mottled shales, and fine green-brown sands with some lignite partings and much hornblende and magnetite, followed by a thick section containing mottled gray and reddish brown shales with coarse to pebbly sands (Fig. 14).

In the area of the Río Opon the Real series as shown by Wheeler consists of a 100-foot conglomerate followed by massive coarse sandstone and gray, blue-mottled red shales resting unconformably on the Oligocene Colorado shales. This formation is called the Lluvia and is 1,600 feet thick. Overlying the Lluvia is a section 4,200 feet thick consisting of gray- and red-mottled shales with thin sandstones and called the Chontorales shale. The Chontorales shale is followed by a 3,500-foot section known as the Hiel formation and containing fine to conglomeratic sands with silicified and carbonized tree trunks. The Hiel is also characterized by an abundance of hornblende and magnetite which was first encountered in the sands of the Chontorales formation. Overlying the Hiel is the Enrejado formation consisting of gray, purple, red- and brown-splotched shales with some fine interbedded sands. Abundant hornblende is also present in the sands of this formation which is 1,500 feet thick. The youngest of the Real series is the Bagre formation. It consists of blue and greenish blue sandstones that are in places pebbly and conglomeratic. Carbonized wood and leaves and some silicified wood are present.

North of the Sogamoso River at Aguas Claras, the Honda formation, consisting of fine to very coarse gravelly gray-brown and grayish white sands and bluish gray to olive-green silty shales, has been placed in the Miocene (Fig. 13).

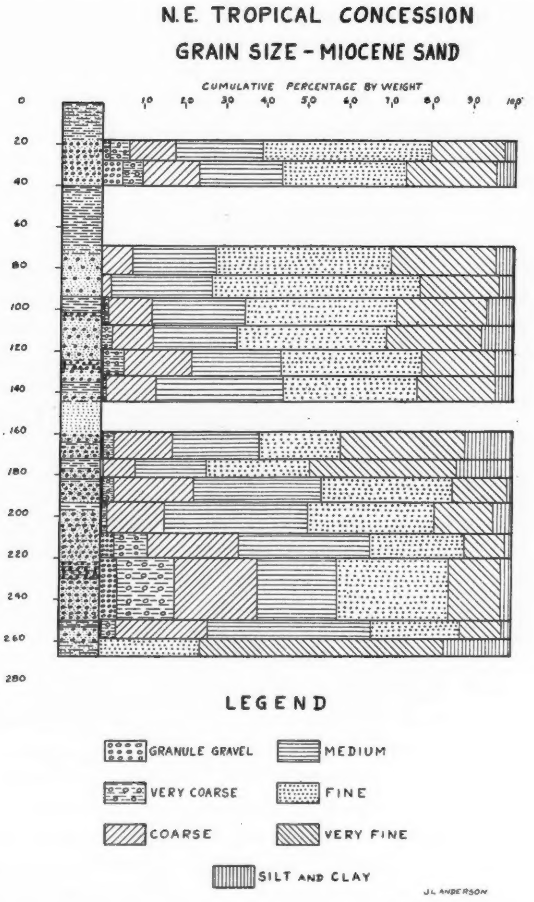


FIG. 14.—Columnar section and grain size. Miocene sand, De Mares Concession, Colombia. Depths in feet.

The La Cira fossil zone is missing and coarse to gravelly sands rest on Colorado-type shales. The Honda formation of this area is characterized by an almost entire lack of hornblende which is common in the Miocene farther south. Farther north on the Río Lebrija the Miocene Honda formation becomes very con-

glomeratic and large boulders of sedimentary and igneous rocks are common. Shales of various colors are present in boulder and sandy zones. The thickness of the Honda formation on the Río Lebrija is in excess of 10,000 feet. Hornblende is typically absent.

Pliocene.—The period of Miocene sedimentation in the Magdalena basin was followed by a period of uplift and erosion. The Miocene beds suffered both folding and faulting and the overlying Pliocene Mesa beds were deposited unconformably over them. The beds of the Mesa formation in the middle Magdalena Valley are composed of fine-grained to coarse sands and pale clay shales. In the area of the Río Sogamoso green and brown hornblende are important constituents of the sands. Farther south in the vicinity of the Río Opon, amphiboles and pyroxenes are important constituents. Wheeler points out that there is evidence for post-Mesa faulting at the town of Honda.

Quaternary.—Stream gravels form the banks of the present drainage channels of the Magdalena River and its tributaries. Several different terraces are discernible along some of the tributaries and the gravels are found as much as 200 feet above the present stream levels. These extensive stream-gravel deposits are known as the Magdalena formation by geologists of the Tropical Oil Company and have been named the Sabana gravels by workers north of the Río Sogamoso.

UPPER MAGDALENA VALLEY

Eocene.—Eocene deposits are well known in the upper Magdalena Valley. They were first recognized by Karsten (1886) who described them in the vicinity of Bogotá and Guaduas. In this area, Karsten noted sandstones, conglomerates, and shales containing fossil remains. Upper Cretaceous Foraminifera were found by him in the conglomeratic facies. Karsten noted further that these beds rested discordantly on the underlying Upper Cretaceous Guadalupe sandstones and referred them to the Tertiary.

Hettner (1892) gave the name Guaduas to these Tertiary beds but did not admit that there was an unconformity between them and the underlying Cretaceous. The Guaduas as described by Hettner in the plateau country consists of variegated clays and intercalated coarse red and white sands and conglomerates. Coal deposits were reported from the lower part of this series. Fossil remains from a dark gray carbonaceous shale from San Juan de Río Seco, and east of Girardot (Anderson, 1927, p. 604) contain forms found in the Los Corros horizon at the top of the Eocene in the middle Magdalena Valley. The thickness of the Guaduas in the plateau area as reported by Scheibe is more than 6,500 feet.

The Guaduas formation is widespread in its development in the upper valley. It is well known on the plateau in the vicinity of Bogotá and northeast toward Tunja, as far south as Girardot on the Magdalena River, and on the eastern flank of the Cordillera Oriental in the vicinity of Medina. Its general distribution suggests that it might be connected with the coal-bearing Eocene of southwestern Venezuela.

The lithologic character of the Eocene of the northern coast and Magdalena Valley areas indicates that marine conditions prevailed only in the extreme northern part of the country. Even here the evidence indicates that swampy conditions favoring the formation of coaly material and elevations sufficiently high to give rise to coarse clastics were present during the period of marine invasion. In the middle and upper parts of the Valley the evidence indicates that during Eocene time the mountains, especially the Cordillera Oriental, were not high and uplift was taking place in local areas. The type of deposits found in the Eocene of the middle and upper Magdalena Valley suggests deltaic environments. The mineral content of the Eocene sediments from the Río Lebrija at least as far south as the Río Ermitaño is similar and is a metamorphic suite. Although the Eocene sediments do show a thickening and an increase coarseness of grain from west to east, as indicated by Wheeler (1935), they could not have been derived from rocks cropping out in the then Cordillera Oriental as no metamorphic rocks containing the minerals now found in the Eocene sands are known to occur there. It is believed that the Cordillera Central yielded little material to the Eocene sediments. Since it is strongly suggested that the region of the present Cordillera Oriental was in general an area in which sedimentation kept pace with subsidence thus preventing marine condition from invading the Valley, the sediments which comprise the Eocene must therefore have been derived not from the Cordillera Oriental as known today but from a source located in the southeast and south. The present Magdalena Valley, therefore, is a post-Eocene phenomenon. The folding and faulting of the Guaduas of the upper valley also supports this view (Notestein, in Schuchert, p. 640).

Oligocene.—Butler (1942) has described Oligocene beds belonging to the upper part of the Colorado series along the Cundinamarca Railroad. Here the sequence is soft, light-colored sandstone and fine-grained conglomerate, mottled shales, gray-green coarse-grained sandstones, thin sandstones and shales, followed by a 15-centimeter lignite seam, then the La Cira fossil zone, and finally soft shales and coarse-grained sandstones. Near kilometer 196 on the railroad, Butler notes a bed of lignite 1.3 meters thick and 105 meters (344 feet) stratigraphically higher than the fossil horizon. Sandstones overlie the coal.

The two formational names, Gualanday-Barzalosa, introduced by Scheibe for coarse-grained clastic sediments occurring in the region near Girardot, are one and the same formation (Scheibe, 1933a). The exact age and relationship to the Honda beds of Hettner was not established by Scheibe. The Gualanday-Barzolosa beds overlie unconformably the Eocene Guaduas and are possibly Oligocene in age. Butler (1942) has given an excellent review of the current confusion concerning the relationships of the various Upper Tertiary formations, pointing out that the Gualanday-Barzolosa have not been traced into the Honda formation.

Miocene.—The Miocene of the upper Magdalena Valley is known as the Honda series, a name which has caused great confusion in Colombian stratigraphy. Butler (1942) has traced the history of the use of the term Honda since its

introduction by Hettner in 1892 and has made recommendations concerning the future use of the term with which the writer of this article is in agreement.

The Honda series as described by Butler consists of an upper and a lower unit. The upper Honda is characterized by the presence of conglomerates consisting of pebbles of andesite, dacite, and porphyry. Black chert and quartz pebbles are also abundant. The thickness of this unit is more than 2,400 meters (8,000 feet). The lower Honda consists of sedimentary conglomerates with andesite and dacite missing, sandstones, shales, and claystones. The thickness of this unit is about 1,600 meters (5,248 feet).

Butler refers to the presence of abundant hornblende and slightly less abundant black opaque as a characteristic feature of the Honda series, especially its upper portion, and its rare occurrence in the bottom part of the series. This is in agreement with the mineralogy of a section studied by the author in the vicinity of the Ríos Carare and Horta (Fig. 13). In this section, hornblende is absent to very rare in the basal 1,575 meters (5,166 feet). In the overlying 1,545 meters (5,067 feet) hornblende wedges in and out, but overlying this section there are 1,970 meters (6,461 feet) in which there is a flood of hornblende. The youngest formation of the Real series in this area is known as the Bagre which overlies the rich hornblende zone. There is an abrupt ending of the rich hornblende zone marking the base of the Bagre and for 573 meters (1,879 feet) a new suite of minerals comes in and hornblende is rare. The hornblende zone of the upper Honda series is therefore about 3,500 meters (11,480 feet) thick and is underlain by a barren to very rare hornblende zone constituting the lower Honda.

The Honda series along the Cundinamarca Railroad according to Butler lies conformably on the Colorado series. The same condition exists in the La Cira oil field area but in Río Opon region, the La Cira fossil zone is missing and a unconformity is evident. Weiske (1938) also reports an unconformity between the Honda (Girardot) and Barzalosa (Oligocene) near the town of Girardot.

The nature of the Honda series indicates that it is continental in origin. In the upper Magdalena Valley, the composition of the series indicates that the source of the sediments was from the west. The thick hornblende-bearing zone of the Honda series of the upper valley decrease toward the middle part of the valley and north of the Río Sogamoso at Aguas Claras, it is practically absent. It is not recorded on the Río Lebrija where pleochroic andalusite and blue and colorless corundum are important. In the middle Magdalena Valley both north and south of the Río Sogamoso there is a mixing of the sediments, the source being both from the southwest and east.

Pliocene.—The Pliocene of the upper Magdalena Valley is represented by the Mesa formation which consists of fragments of pyroclastic material such as andesite, dacite, ash, pumice, all more or less indurated. Coarse-grained sandstones and agglomerates are very common and beds of clay and fine-grained sand occur in places. Here and there large boulders of igneous and metamorphic rocks are present at various horizons. Fossil leaves and tree trunks are reported by

Butler (1942) in the Mesa of the Honda district. The thickness is according to Butler from 226 to 350 meters (741 to 1,148 feet).

The Mesa formation is different from all older formations in that it is characterized by an abundance of pyroclastic material. It is continental in origin and represents an alluvial-plain type of deposit formed by streams flowing from the Cordillera Central into the Magdalena River.

In the upper Magdalena Valley, the Mesa formation forms conspicuous hills from La Dorada southward to Cambao according to Butler. It is also reported from the upper reaches of the Magdalena and as far north as at least Puerto Berrío. Although it is not definitely known whether the typical Mesa formation extends as far north as the region north and south of the Sogamoso River, the equivalent of the Mesa in this area is characterized by the presence of green and brown hornblende, glaucophane, pyroxenes, epidote, garnet, titanite, a mineral suite which doubtless had its origin in the Cordillera Central.

Pleistocene.—Butler (1942, p. 825) describes the Gualí formation which unconformably overlies the Mesa and to which he has assigned a Pleistocene age. The Gualí formation is considered to be an alluvial-plain deposit consisting of eroded material from the Mesa and other formations. Butler reports the Gualí from as far south as Ambalemba, within the water gap at Honda, and as far north as La Dorado.

General Depositional and Diastrophic History

The marine limestones and shales and coarse clastics of the early Cretaceous were followed by coarse clastic and volcanic material of the late Cretaceous in southern Andean basin and shallow-water and swampy conditions favoring coal formations farther north in the central and northern portions of the basin. The Cretaceous was brought to a close by broad epeirogenic movements which uplifted certain areas and exposed them to moderate erosion and folding. Local areas show angular unconformities between the Cretaceous and Tertiary while in others, sedimentation continued uninterrupted into the Tertiary.

The transition between the Cretaceous and Tertiary is characterized by the development of coal beds in the lower Eocene of the upper and middle Magdalena Valley. With the withdrawal of the Cretaceous sea, marine conditions did not prevail again in the Magdalena Valley north of El Banco. Fossils found at the top of the Eocene in the middle and upper valley are non-marine in origin. The absence of marine conditions indicates either that sedimentation was able to keep pace with the downwarping of the basin or a "high" existed in the middle Magdalena Valley, thus forming a non-marine basin of deposition in the southern part of the valley. The thickening of the Eocene toward the east and the mineral content of its sediments strongly suggest that the Eocene was continuous over the present Cordillera Oriental. A marine environment existed during Eocene time in northern Colombia but was interrupted occasionally by coal-form conditions. Toward the close of the Eocene, uplifting, folding and faulting marked the

beginning of the formation of the Cordillera Oriental and the Magdalena Valley.

The Oligocene of the upper Magdalena Valley is characterized by coarse clastics and interbedded shales. In the middle Magdalena Valley, non-marine shales and medium- to coarse-grained sands predominate. These sediments show a decided thickening toward the east but since the mineralogy is different from the underlying Eocene, it is considered that the source of the material was in the Cordillera Oriental and not farther toward the east and south. Two fossil horizons, characterized by the presence of brackish-water forms and river snails occur in the Oligocene. Differential uplift produced a local unconformity at the top of the Oligocene in the middle Magdalena Valley. The Eocene and Oligocene non-marine sediments have the general appearance of deltaic deposits. The middle Oligocene of northern Colombia indicates a near-shore environment where coarse clastics were deposited. Deeper-water conditions with the formation of marine shales and limestones characterized the upper Oligocene of this area.

The Miocene of the upper and middle Magdalena Valley is typically alluvial in nature. The Cordillera Oriental was undergoing pronounced uplift or conversely the Magdalena Valley was being greatly depressed. The sediments of this period were derived both from the Cordillera Central and the Cordillera Oriental. The period of intense Miocene sedimentation was brought to a close by pronounced revolutionary events in the Northern Andes. Intense uplift and erosion, which carried on into the Pliocene, folding and faulting on a large scale, and violent volcanic activity in the Central Cordilleras marked the close of the Miocene and the beginning of the Pliocene. The present character of the Magdalena Valley is largely the result of this revolution. In contrast to the non-marine alluvial deposits of the middle and upper Magdalena Valley are the marine shales, limestones, and sandstones of the northern part of Colombia. Marine Miocene conditions did not prevail south of El Banco on the Río Magdalena. Local unconformities separate the Miocene and Pliocene in northern Colombia.

Volcanic activity in the early Pliocene produced tuffaceous deposits in the upper valley, while marine conditions existed in the northern part of the country. The Pliocene of the middle and upper valley was deposited unconformably on the Miocene and is a typical alluvial deposit, the material being derived both from the Cordillera Oriental and from active volcanoes of the Cordillera Central. The early Pliocene of the central and southern portions of the country was a period of profound dislocation. Uplift, folding, and faulting took place in many instances along older lines of dislocation producing the general configuration of the valley and the Cordillera Oriental.

Following the period of intense vulcanism which brought the Pliocene to a close, came a period of uplift and erosion without further volcanic activity. In the upper valley, some of the Pliocene sediments were removed and deposited in rivers flowing toward the Río Magdalena. This period of erosion and slight uplift probably belongs to the Pleistocene. Recent movements both in the valley and along the northern coast have resulted in the formation of a system of terraces.

In the middle and upper valley particularly, there is evidence of several periods of uplift during recent time. In 1944, the Servicio Geológico Nacional of the Ministerio de Minas y Petroleo published the first comprehensive geological map of Colombia. This map shows the distribution of the various geological formations in colors. The map is in considerable detail but unfortunately no structure symbols were included.

Petroleum Geology and Development

General.—The distribution of the sedimentary rocks of Colombia provides a basis for dividing the country into six potential petroliferous provinces (Fig. 15): (1) the Río Magdalena Valley, (2) the Southwestern Maracaibo Basin—Barco Concession, (3) the North Coast area, (4) the Llanos area, (5) the Río Atrato Valley, and (6) the Southwestern Coastal Plain.

RIO MAGDALENA VALLEY

The Río Magdalena Valley area can be divided into two parts: one known as the middle Magdalena Valley lies between the towns of El Banco and La Dorada; and the other, known as the upper Magdalena Valley, extends southward from the town of La Dorada. The middle Magdalena Valley is at present the most important district and the bulk of the Colombian oil has been produced in this region.

MIDDLE MAGDALENA VALLEY. TROPICAL OIL COMPANY'S DE MARES CONCESSION

The most important producing region in Colombia is located approximately 300 miles from the mouth of the Magdalena River and 15 miles southeastward from the port of Barrancabermeja in the Department of Santander del Sur on what is known as the De Mares Concession of the Tropical Oil Company (Fig. 16). The concession lies between the Sogamoso and Carare rivers and extends approximately 30 miles eastward from the Río Magdalena.

Six potential structures have been tested and all but two have been abandoned as non-commercial (Fig. 17).

Two structures, known as Infantas and La Cira, produce all the oil of the De Mares Concession. These two structures are *en échelon*-faulted anticlines trending roughly in a N. 15–20° E. direction.

Infantas field.—The Infantas field is located on a faulted anticline with the fault plane dipping 40°–50° E. (Fig. 18). Faulting has exposed the C zone of the Eocene Chorro series on the east side while on the west, the surface sediments are of the Oligocene Colorado and Mugrosa series (Fig. 19). The beds exposed along the fault are overturned in many places and large seeps which led to the discovery of the field are common (Fig. 20). The discovery well was drilled in 1918 at Infantas on the Río Colorado.

The Infantas field is about 7 miles long with the average width just under one mile. The long narrow structure is divided into a series of fault blocks by 14 more

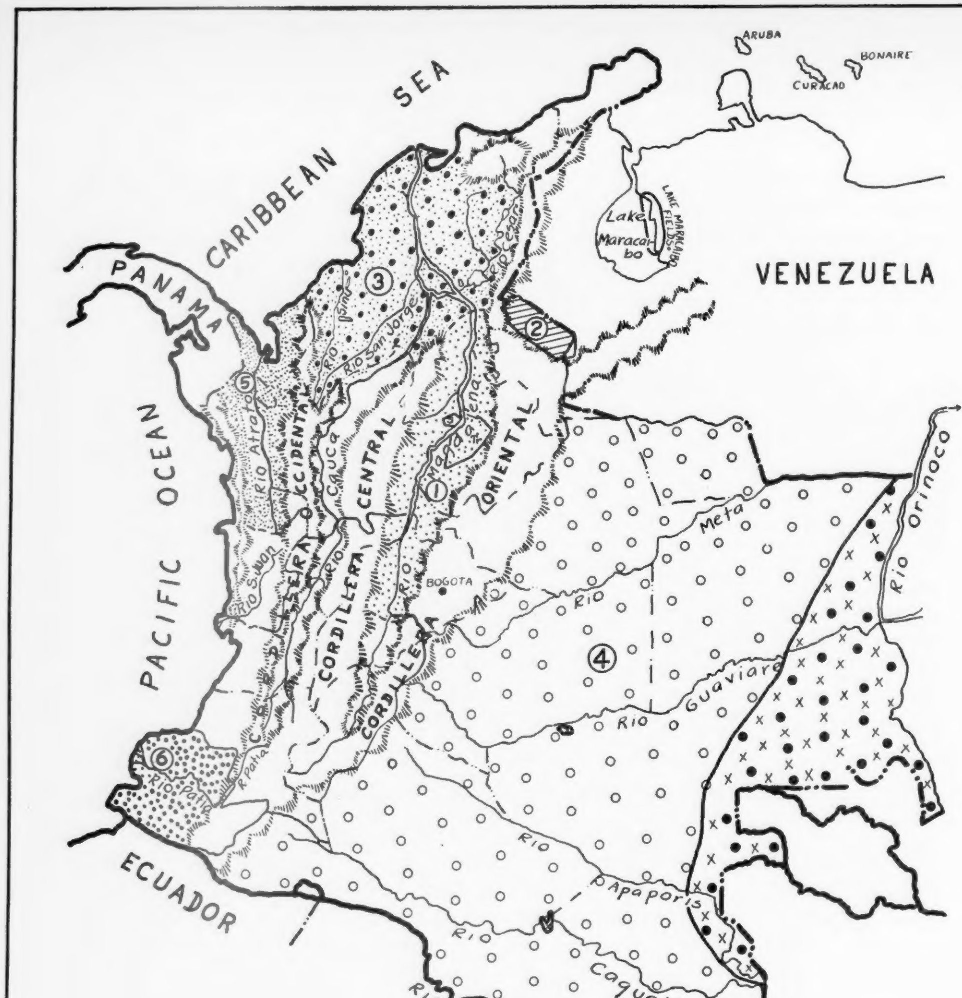


FIG. 15.—Petroliferous provinces, Colombia.

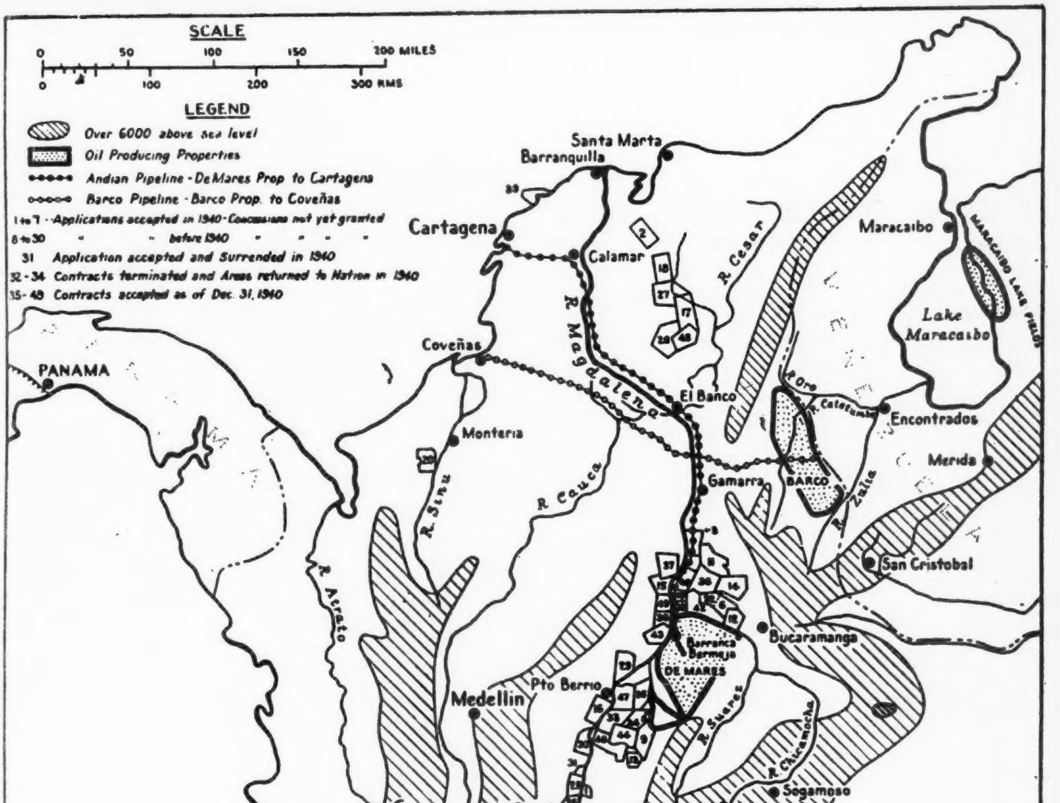


FIG. 16.—Petroleum and gas fields and new concessions, Colombia. (From O. C. Wheeler, *Trans. A.I.M.E.*, Vol. 142, 1941.)

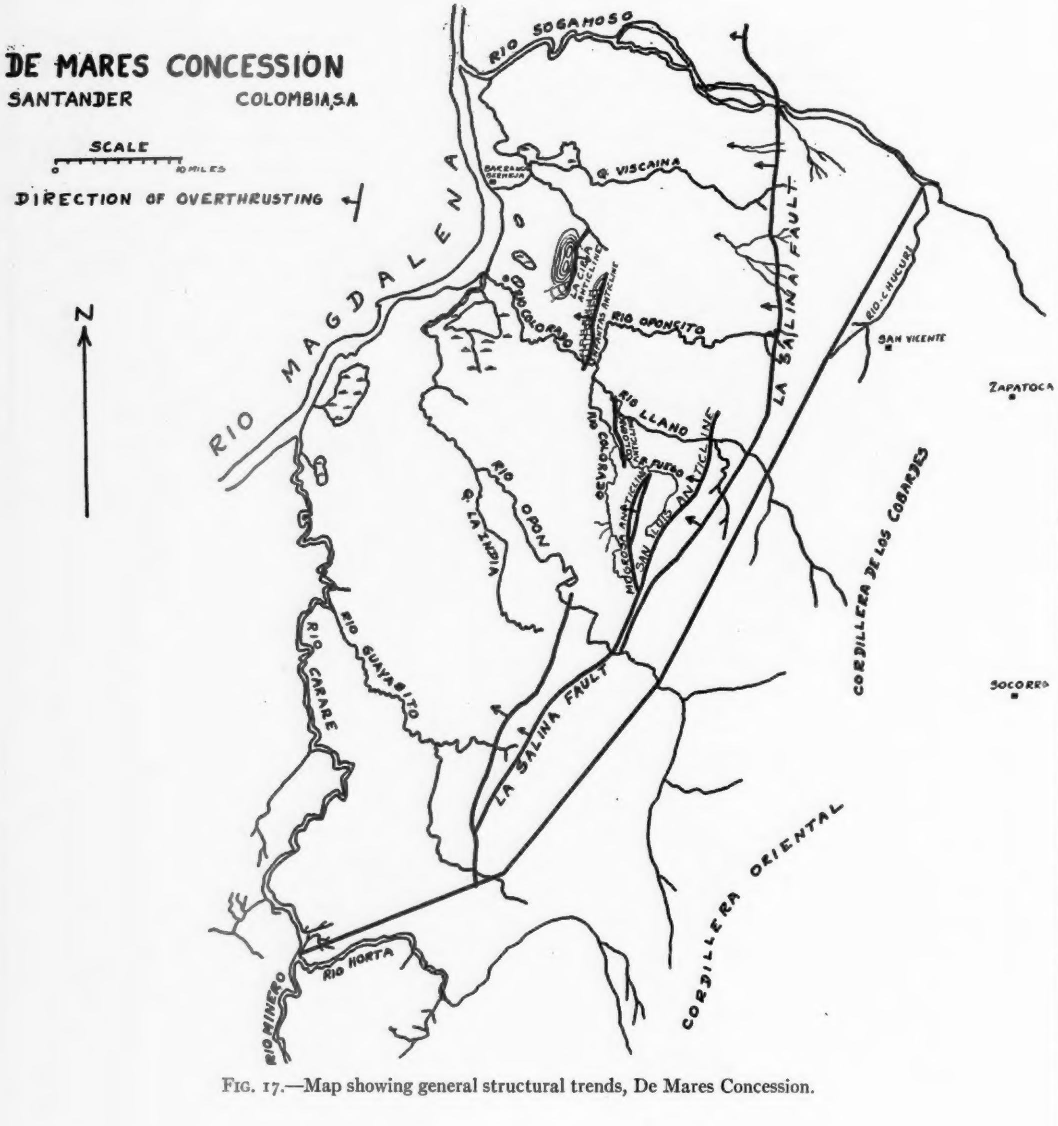


FIG. 17.—Map showing general structural trends, De Mares Concession.

or less east-west trending faults which die out against the main north-south overthrust. Some block faulting is also known to occur on the east side of the main overthrust.

There are two producing zones in the field, the most important of which is the C zone of the Eocene Chorro series lying west of or on the downthrown side of the main fault. The average depth to the top of the sand is 2,200 feet and the bottom is 2,600 feet. The sand is predominantly medium- to fine-grained, the porosity

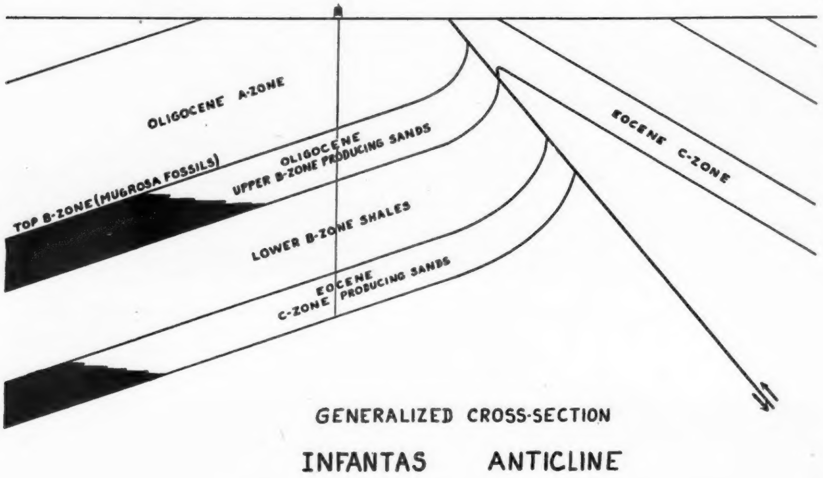


FIG. 18.—Generalized cross section of Infantas structure, Colombia.

varying from 15 to 22 per cent. The gravity of the oil produced ranges from 23° to 35° A.P.I. at 60° F. The oil is asphaltic in base with about 0.9 per cent sulphur.

Drilling for C zone production has been completed on the Infantas structure with a total of 471 wells having been drilled to the end of 1941. Of these, 3 are flowing naturally, 339 are pumpers, 99 were closed in, and 30 abandoned. The total production at the end of 1941 was 130,810,695 barrels and the daily yield for the field was 10,039 barrels of oil as of January 1, 1942. The proved area of the structure is about 5,300 acres.

Deep drilling for the purpose of exploring the Cretaceous has not been successful at Infantas. Drilling on the east side of the Infantas fault for the purpose of testing the Eocene C zone was also a complete failure.

A small amount of Oligocene B zone oil is produced from the north end of the Infantas structure. Wells begin in the Colorado series and encounter a thin zone of calcified molds and casts of gastropods belonging to the Mugrosa fossil horizon which serves as a datum plane from which the sand penetration is measured. The

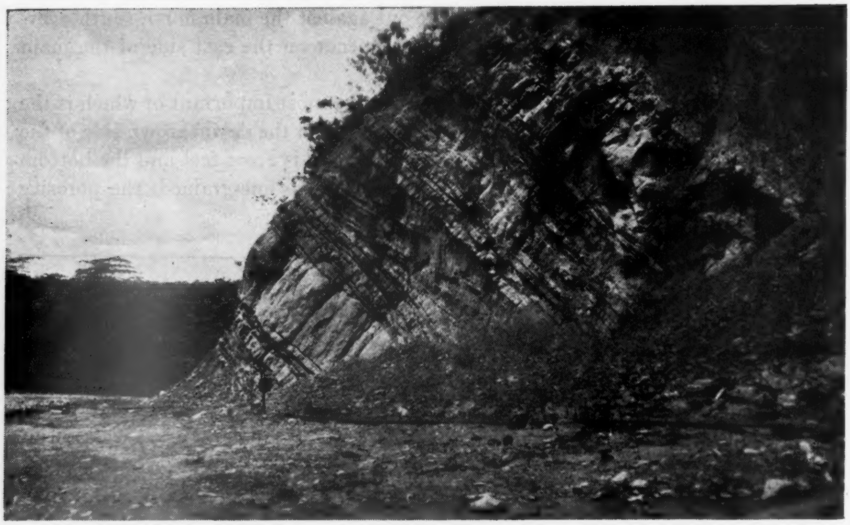


FIG. 19.—Massive and cross-bedded east-dipping Eocene sandstones on east side of Infantas fault, Colombia.

FIG. 20.—Overturned east-dipping Eocene sandstones on east side of Infantas fault.

zone penetration is about 400 feet and the average depth of the wells is close to 1,500 feet. The oil is of asphalt base and has a gravity of approximately 20° A.P.I.

La Cira field.—The La Cira anticline was discovered in 1926. Vertical beds of oil-stained sand in the railroad excavation near the El Centro campsite led to a careful study of the area and the discovery of the structure. Pronounced seepages commonly found along the Infantas fault are lacking at La Cira.

The La Cira field is approximately 5 miles long by 4 miles wide and appears to be a northeast-southwest trending asymmetric anticline (Fig. 21). In contrast with the Infantas structure which is overthrust toward the west, La Cira has its steep face toward the east with the axial plane dipping west. There is some north-south faulting along the east side of the structure, but it is not as pronounced as at Infantas. Several subsidiary more or less east-west faults are also known.

There are three producing zones on the La Cira structure and, like Infantas, the Eocene or C zone, yields the bulk of the oil. The sands of the C zone are predominantly fine- and medium-grained, becoming coarser-grained near the top of the zone (Fig. 22). The average porosity of the C zone sands is 21 per cent. The depth to the top of the zone ranges from about 2,200 to 4,100 feet and the penetration into the zone will average approximately 300 feet. Approximately 50 per cent of the penetration is sand, and the remainder hard blue- and gray-mottled shale and sandy shale.

La Cira C zone crude ranges in gravity from 20° to 25° A.P.I. and is asphaltic in base with 0.9 per cent sulphur. Encroaching edge water governs the amount of penetration into the zone and wells near the edge water frequently produce emulsion.

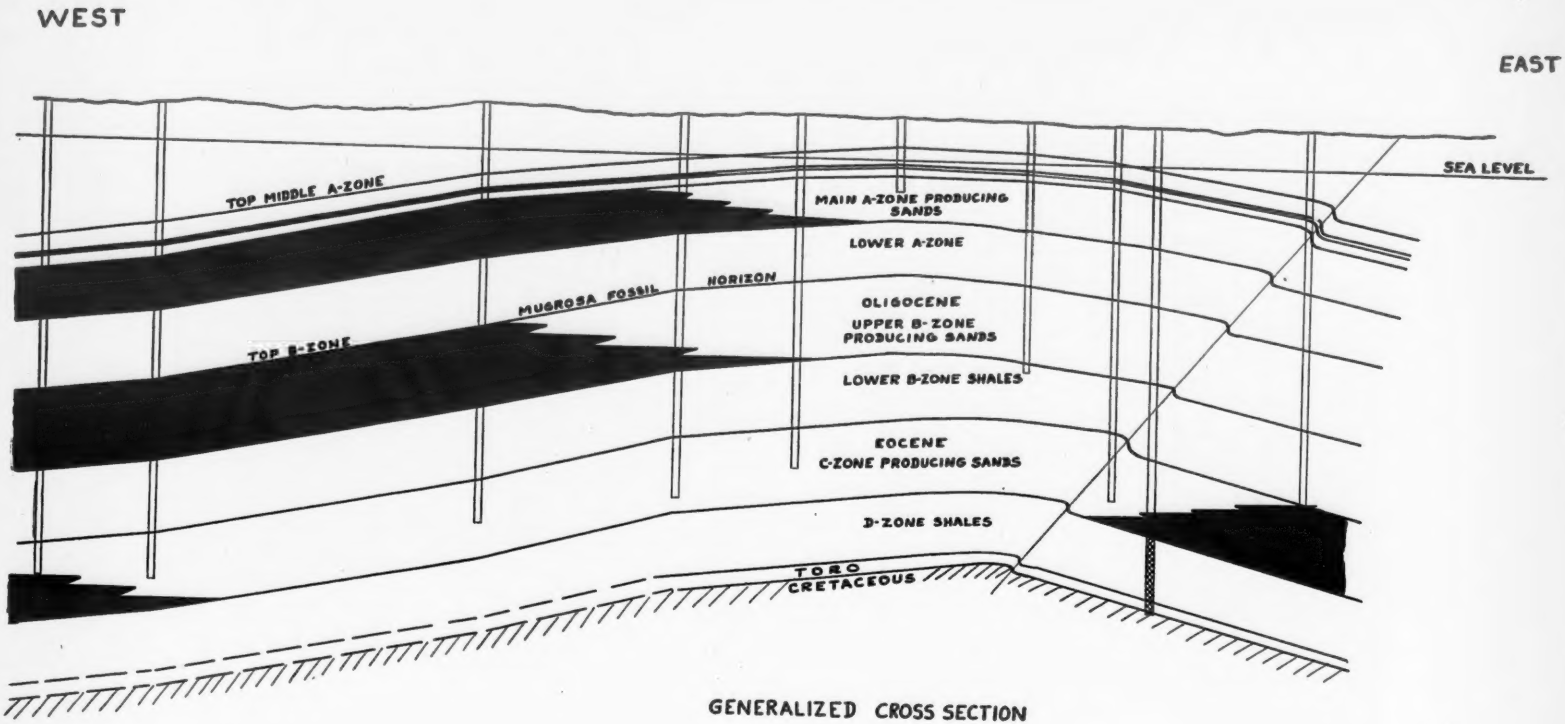
The Los Corros fossil horizon marking the top of the Eocene is absent both on the La Cira and Infantas structures. A change in the mineral suite passing upward into the Oligocene is noted at La Cira and on a basis of mineralogy, the upper part of the C zone has the appearance of the Esmeraldas formation of the upper Eocene north of the Sogamoso River.

The upper 500 to 600 feet of the Mugrosa series of Oligocene age known as the upper B zone, the top of which is marked by the Mugrosa fossil horizon, is also an important productive zone at La Cira. The depth to the top of zone ranges from about 1,100 to 1,600 feet and the bottom of the zone from about 1,700 feet to 2,000 feet.

The sands of the upper B zone are predominantly medium- and fine-grained. Near the top and at the base of the zone, they become decidedly coarser and in places gravel beds have been found at the base (Fig. 23). The average porosity of the B zone sands is about 22 per cent.

The gravity of the upper B zone oil is very near that of the C zone and the base is also asphaltic. The lower B zone has revealed small showings in thin sands but no oil is produced from this part of the section.

The lower portion of the Oligocene Colorado series also yields small produc-



GENERALIZED CROSS SECTION

LA CIRA ANTICLINE

FIG. 21.—Cross section of La Cira structure, Colombia.

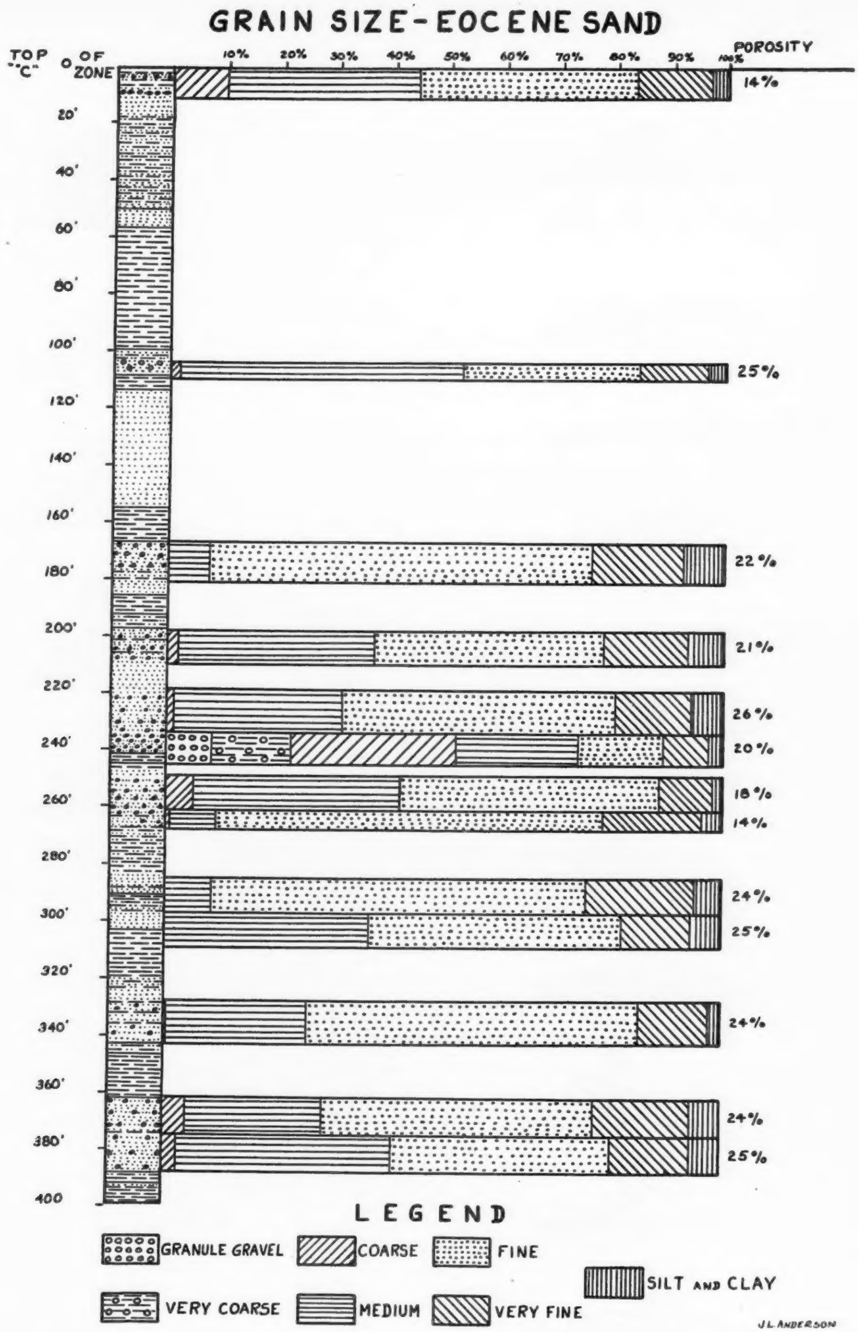


FIG. 22.—Columnar section and grain size of Eocene sand, De Mares Concession, Colombia.

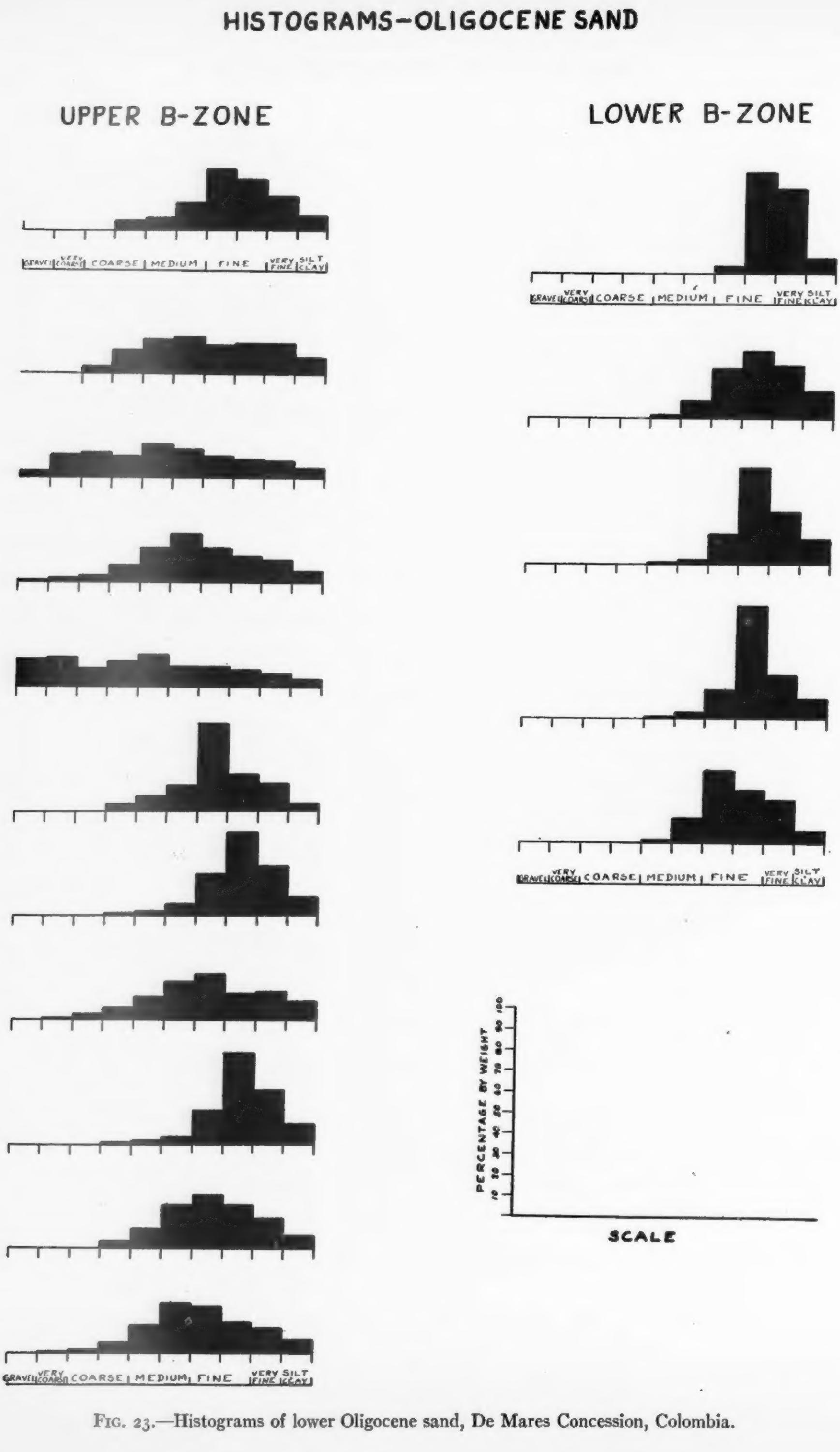


FIG. 23.—Histograms of lower Oligocene sand, De Mares Concession, Colombia.

tion at La Cira. On the northwest flank of the structure the sandy section known as the middle A zone is 1,350 feet below the base of the La Cira fossil zone and 550 above the Mugrosa fossil horizon. On the northern part of the crest of the structure this sandy section is 580 feet thick and lies 435 feet above the top of the B zone while on the southern crest it is 490 feet thick and lies 525 feet above the B zone. Drilling for A-zone production ranges from about 600 to 1,000 feet and the productive section varies from 30 to approximately 350 feet in thickness. The sands are variable in grain size but are predominantly medium- and fine-grained. They are not as coarse as the sands of the upper B zone. The main sand body in the lower part of the middle A zone is continuous from flanks to crest but in the upper part of the zone there is a decided thinning and a change lithologically to fine-grained and silty types.

The oil from the A-zone section is also asphaltic in base but is heavier than either the B- or C-zone oil.

Drilling for the purpose of exploring the Cretaceous has not been successful at La Cira. One well which has been put down in the field to a depth of 8,051 feet encountered no commercial production. A second well northwest of La Cira and about 5 miles from the town of Barrancabermeja was drilled to 7,570 feet but failed to produce any Cretaceous oil.

The proved area at La Cira is in excess of 5,000 acres. In all, 691 wells have been drilled at La Cira at the end of 1941. Of this total, 33 were flowing naturally, 539 were pumping, 99 were closed in, and 20 had been abandoned (*Oil Weekly*, July 27, 1942). The total production at the end of 1941 was 161,164,928 barrels of crude with a daily average production of 50,352 barrels.

During the early development on the Infantas structure drilling was done by cable tools. This method was superceded by rotary tools in all fields after the first 20 to 30 wells were drilled. The heavy dense jungle growth has to be cleared and roads built to all drilling locations (Fig. 24). Most of the recent wells at La Cira cemented solid casing and were gun-perforated. All recent wells have been electrically logged.

Both the La Cira and Infantas fields have been entirely electrified and all pumping wells are electrically operated (Fig. 25). Wet gas is piped to a central plant located at El Centro where it is treated. The dry gas is used as fuel both for drilling and domestic consumption and a large portion of the remainder is put back into the producing zones for repressuring. A part of the petroleum condensate derived from the treatment of the wet gas is added to the crude before shipment to the coastal terminal.

Most of the crude at both Infantas and La Cira is of the low cold-test variety with only a small amount of high cold test present. Much of the Infantas and La Cira crude contains emulsion and is treated in two dehydration plants located in the field (Zwick, 1941).

A small refinery with a capacity of about 15,000 barrels per day is located at the Tropical's camp at the river port of Barrancabermeja. The output from this refinery is used to supply the local demand for refined products.

FIG. 24.—Clearing of dense jungle and new road to drilling site, De Mares Concession, Colombia.

FIG. 25.—Power plant and warehouses, El Centro Camp, Tropical Oil Company.

The crude output from the De Mares concession is pumped from El Centro to the ocean terminal at Mamonal near Cartagena by the Andian National Corporation, a common carrier and an affiliate of the Tropical Oil Company (Fig. 26). The pipe line is an almost completely looped 10-inch line built in 1926–1927 with a daily capacity of 55,000 barrels (Fig. 16). The length of the line is 335 miles, laid through swamp and jungle with nine booster-stations along the length of the line. The original cost of the single line is reported to be approximately $20,000,000. Ocean-going tankers load at the terminal in Cartagena.

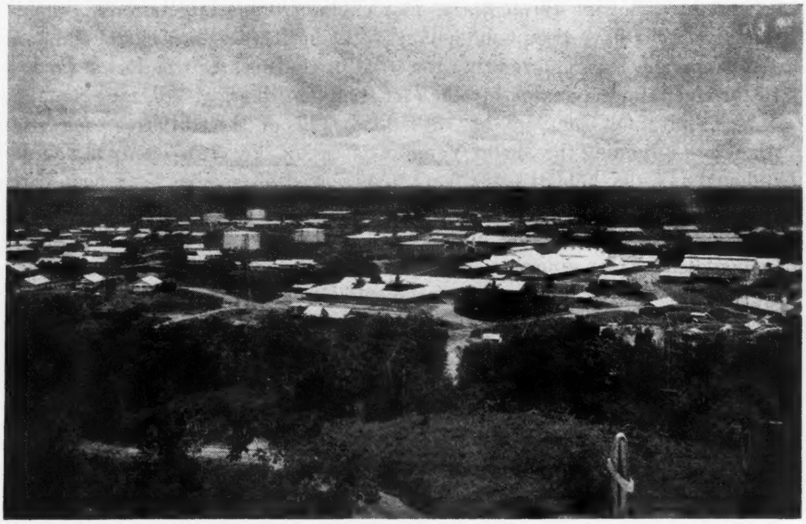


FIG. 26.—Portion of El Centro Camp, showing main office, tank farm, and part of main gasoline plant, Tropical Oil Company.

MIDDLE MAGDALENA VALLEY. WEST SIDE

Casabe field (Fig. 16).—The bringing in of Shell's Casabe No. 1 at the total depth of 8,280 feet on the Yondó Concession on the west side of the river opposite the De Mares Concession in October, 1941, attracted considerable attention to this region. The structure is reported to be highly fractured and complex (E. Ospino-Racines, 1943) and completed wells are reported to be 3,600 to 7,600 feet in depth. Several producing zones are indicated, one of which corresponds with the C zone (Eocene) of the De Mares Concession. The initial production of the wells ranges from 200 to 1,200 barrels per day of 21° to 24° A.P.I. oil. Twenty-three producing wells have been completed to December, 1944, proving an estimated reserve of over 100,000,000 barrels. The field has a daily potential production of 15,000 barrels which was tied into the Andean National's pipe line on

June 6, 1945. The discovery of this field is one of the most important finds in Colombia in recent years, the exploitation of which runs to 1895.

Cantagallo Concession (Fig. 16).—The Socony-Vacuum has succeeded in finding a field in the Río Cimitarra region on the west side of the Magdalena River approximately 15 miles north of the Shell's Casabe field. Like the Casabe area, this area is reported to be highly fractured and complex. The first well encountered gas at 1,013–1,018 feet, flowing at the rate of 240,000 cubic feet a day through a $\frac{3}{8}$-inch choke. Small showings of heavy oil were also reported (J. V. Hightower, 1942). This well was later completed as a 261-barrel-per-day 20° A.P.I. producer flowing through a $\frac{3}{16}$-inch choke (*Oil and Gas Journal*, June 24, 1944). Five wells have been completed, two being in the 3,000-barrel class and three abandoned. It is reported that the structure in this area trends eastward toward the river and may extend to the east shore (*Oil Weekly*, Vol. 116, No. 2).

The Tropical Oil Company has drilled two wells on the Gutierrez Concession north of and adjoining the Shell's Yondó Concession (Fig. 16). The first well was abandoned as a dry hole at 9,285 feet. No reported discoveries have been listed from this area.

The Richmond Petroleum Company also drilled two wells on the west side of the Magdalena River approximately 50 miles north of the Shell's Casabe field (Fig. 16). One well encountered the basement at 2,069 feet and was abandoned as a dry hole. The second well was also abandoned as a dry hole at 2,812 feet. The Richmond is reported to be ready to drill on the west bank of the Magdalena River near La Dorada, about 150 miles south of Barrancabermeja (*Oil Weekly*, Vol. 116, No. 2).

The Phillips Petroleum Company is reported ready to explore its holdings on the west bank of the Magdalena River near the town of Simití, approximately 60 miles north of the Casabe field (Fig. 16).

MIDDLE MAGDALENA VALLEY—EAST SIDE; SOUTH OF DE MARES CONCESSION

Sociedad Nacional del Carare (Fig. 16).—Two wells were drilled by this company on the Carare Concession southeast of Puerto Berrío and both were abandoned as non-commercial. San Fernando No. 2, located on a structure with good anticlinal closure, started in the Real series of Miocene age and ended at 9,272 feet in the La Paz Eocene. The well is reported to have encountered small showings of oil but was abandoned as non-commercial (Wheeler, 1941). The company drilled its Monte Oscuro No. 1 to the total depth of 6,550 feet, abandoning it as a dry hole. This well was also located on a well developed faulted structure and was drilled into the basal Tertiary sands. As a result of these two tests, the company abandoned its concession.

Shell Oil Company.—This company drilled two wells on its Monte Oscuro structure south of the Carare Concession and both were abandoned as dry holes (Fig. 16). The structure is a faulted anticline with an east-dipping fault plane. Well No. 1 started in the Armas formation (Oligocene), crossed the fault at 2,956

feet, and ended in the La Cira formation at 9,103 feet. Well No. 2 started in the Armas formation (Oligocene), encountered the fault 2,454 feet, and ended in the Real series (Miocene) at 3,016 feet on the west side of the fault (Wheeler, 1941).

The Shell also drilled a test well on an anticline west of the Carare River and northeast of Puerto Berrío, known as Puerto Parra No. 1. This well started in the Mesa formation (Pliocene) and ended as a dry hole in the Oligocene at the total depth of 10,929 feet.

Three other wells were drilled by the Shell on the east side of the Magdalena River, in the vicinity of the Río Ermitaño. Baul No. 1 started in the Mesa formation (Pliocene) and encountered the igneous basement at 7,447 feet. The well was abandoned as a dry hole. Zambito No. 1 started in the Mesa formation and ended as a water well at 2,388 feet. Palagua No. 1 was abandoned as a dry hole at 3,520 feet.

It is reported that The Texas Company is ready to drill a test in western Boyacá, 30 kilometers south of Puerto Boyacá. The well is said to be located on a seismic anticlinal structure (*Oil Weekly*, Vol. 116, No. 5).

Thorough testing of the geological section from the Pliocene through the Eocene on well developed structures on the east side of the Magdalena River and south of the De Mares Concession has failed to find commercial production to date.

MIDDLE MAGDALENA VALLEY. EAST AND NORTH OF DE MARES CONCESSION

In all, 26 wells have been drilled on the east side of the Magdalena River and north of the De Mares Concession without developing commercial production (Fig. 16).

Las Monas structure.—Located approximately 50 kilometers east and 15 kilometers south of Puerto Wilches is a faulted anticline with steep-dipping Cretaceous and Eocene beds exposed on the east side of a major fault. On the west side of the fault the beds are also steeply dipping and are Oligocene and Miocene in age (Fig. 27). Eight wells were drilled by the Gulf Oil Company on this structure and only small production was developed (Fig. 28). The Socony-Vacuum drilled 3 wells on the west flank of the structure without producing commercial oil, and abandoned its concession.

La Tigre structure.—This structure is located approximately 70 kilometers east and 25 kilometers north of Puerto Wilches, at the headwaters of the Río Tigre, a branch of the Río Lebrija. The Tigre structure is a faulted, tight, overthrust anticline with steeper dips on the western flank. The Cretaceous on the east is thrust against the La Paz (Eocene) on the west. Eleven wells have been drilled on and near this structure without developing commercial production.

Nariño structure (Fig. 16).—Located about 25 kilometers east of Puerto Wilches is a gentle fold on which the Socony-Vacuum has recently drilled two wells. Nariño No. 1 started in the Pliocene and was abandoned in the Oligocene at 6,516 feet due to mechanical difficulties. Nariño No. 2 also started in the

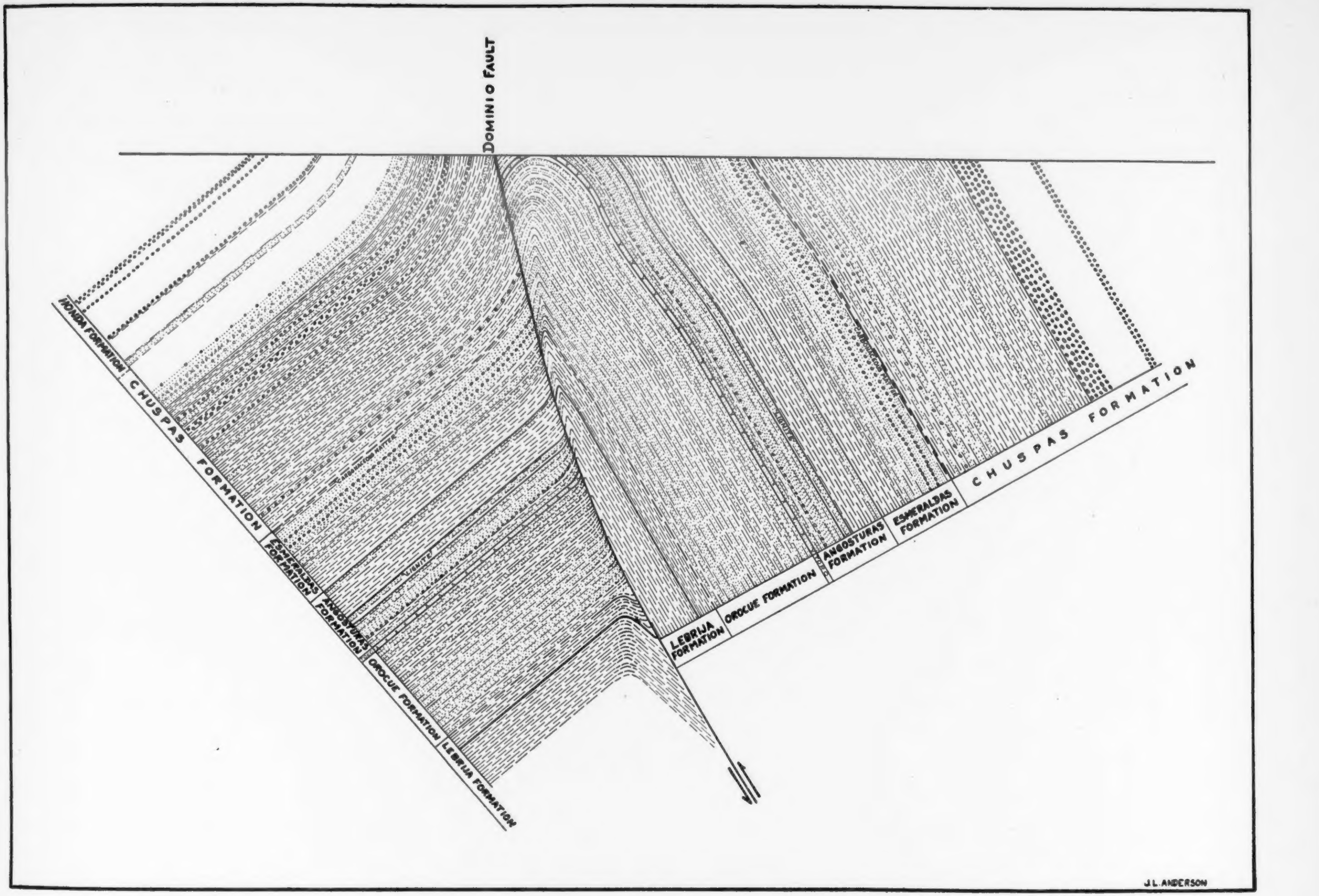


FIG. 27.—West-east cross section of Las Monas structure, Aguas Claras, Colombia. Scale, horizontal and vertical, 1 centimeter equals 100 meters.

FIG. 28.—Seepages along Dominio fault, Las Monas structure, Aguas Claras, Colombia.

Pliocene and was drilled into the Girón at the depth of 10,740 feet. No commercial production was developed in either well.

Peralonzo structure.—This structure is northeast of the Nariño structure, was mapped by seismograph and drilled by the Socony-Vacuum. The well started in the Pleistocene gravels about 10 kilometers northeast of the Nariño structure and was abandoned as a dry hole in the Oligocene at the depth of 9,274 feet.

The Socony-Vacuum also drilled its McCarthy No. 1 on the east shore of the Magdalena River. It was abandoned as a dry hole at 5,600 feet.

Drilling on the east side of the Magdalena River, north of the DeMares Concession has been very discouraging. Well developed structures, in one instance involving beds ranging in age from Pliocene to Jurassic, have been tested but no oil was found in commercial quantity.

UPPER MAGDALENA VALLEY

Complex faulting and folding are characteristic features of both the east and west sides of Magdalena River in the valley south of La Dorada. Numerous tight anticlines with the Cretaceous and Eocene exposed are rather common. Northeast-southwest trending faults of the overthrust type are numerous and divide the area into a series of fault blocks. Beds of Eocene and Cretaceous age are brought to the surface and thrust over Miocene beds as is the case near the town of Honda. Seepages of heavy tar oil and dark green oil are present along the crests of folds and along fault lines on both sides of the river.

Five wells have been drilled in the upper Magdalena Valley, 1 under 1,000 feet, 1 between 2,000 and 3,000 feet, and 3 between 3,000 and 4,000 feet. Small showings of petroleum were reported but no commercial production has been developed.

SOUTHWESTERN LAKE MARACAIBO AREA. BARCO CONCESSION

The only comprehensive geological account of any Colombian producing field is the very interesting and instructive article dealing with the Barco Concession by Notestein, Hubman, and Bowler (1944) which appeared in a recent *Bulletin* of the Geological Society of America. The following is a summary of the salient facts taken from that paper together with a copy of a portion of the map showing the location of the structures. For a more detailed account the reader is referred to the original article which contains an excellent colored geological map.

The Barco Concession (Fig. 16) is in what has been classified as the National Reserved Zone where concessions are granted only by act of the Colombian Congress. The concession was originally granted to General Barco in 1905 and was cancelled in 1926. From 1913 to 1931 geological studies were carried on in the area and the first well was drilled by the Doherty interests on the Río de Oro in 1920. In 1931, the concession consisting of 1,022,000 acres was granted to the Colombian Petroleum Company (Gulf interests) from which 460,000 acres were selected for exploitation. The concession is now controlled and operated by The Texas Company and the Socony-Vacuum Oil Company.

The area, located in the upper Río Catatumbo basin between the Sierra de Perijá and the Sierra de Merida, is reached by railroad from Cucuta to Puerto Villamizar, thence by road to Petrolea, or in the wet season, by barge and launch up the Catatumbo drainage from Lake Maracaibo (Fig. 15). The field is also reached by private plane.

Cretaceous and Tertiary rocks crop out on the concession but no Girón or basal red conglomerate has been observed. The Cretaceous consists of sandstones, limestones, and shales whose thickness varies from 4,156 to 7,100 feet. The Tertiary beds are sandstones of variable grain size, gray and green shales, and some coals. The thickness varies from 6,808 to 11,546 feet.

The principal producing zones of the Barco area are in the Lower Cretaceous and the basal Eocene (Figs. 10 and 13). Five productive zones are known in the

Cogollo limestone and three in the Uribante formation. Porosities are very low and fractures seem to be the controlling factor in localizing the petroleum. Oil and gas seeps are rather common and asphalt dikes are known.

The Barco area is located along the southwestern portion of a northeasterly plunging lobe of the Maracaibo basin between the Sierra de Perijá and Sierra de Merida (Fig. 29). The region is bisected by the Petrolea-Tarra anticlinorium, a prominent structural feature, about 120 miles long, one-third of which lies on the concession and the remainder in southwestern Venezuela. East of the anticliorium is the Zulia depression and on the west lies the Sardinata structural depression. In the Sardinata depression are located several important folds. Eastward overthrusting along the eastern margin of the Sierra de Perijá has produced folds and faults in the foothills.

Four structures are associated with the Petrolea-Tarra anticlinorium (Fig. 29). The Gonzalez anticline is a highly faulted asymmetric anticline with possibly no Cretaceous closure on the south. This structure has not been tested but no oil or gas seeps are known to be present. The Leoncito anticline is a complexly faulted, asymmetric anticline with a steep east flank and a gentle west limb and probably not closed at the north end. The entire Tertiary section is exposed. Drilling has proved the Tertiary to be dry beneath a thrust fault. The Lower Cretaceous has not been tested. The Petrolea anticline is one of the important structures of the Barco Concession. It is a complexly faulted, closed, asymmetric anticline with a steep west face and a gentle east flank. The anticline consists of two parts known as the North dome and the South dome. The entire Tertiary crops out on the anticline. On the North dome, the Cretaceous is exposed to within 65 feet of the La Luna limestone and on the South dome to within 275 feet of the top of the Uribante formation. Oil and gas seeps are numerous on the Petrolea anticline. The North dome is the most productive portion of the anticline. In all, 130 wells have been drilled here on a 40-acre spacing, 124 of which are producers. Six producing zones located in the La Luna, Cogollo, and Uribante formations are recognized. The Petrolea anticline is reported to have a closure of approximately 4,000 feet and a closed area of about 17,300 acres. The wells drill to a depth of 66 to 1,683 feet and the oil from these wells is paraffine in base, varying in gravity from 36.7° to 47.8° A.P.I. The gasoline fraction is reported to be high and the lubricating fraction low. The total production of the Petrolea anticline to December 31, 1942, was 10,896,617 barrels. The field produces about 11,000 barrels of crude daily. The South dome has only seven wells, of which only one is productive. The Carbonera thrust fold is the fourth structure of the Petrolea-Tarra anticlinorium. It is a broad nose truncated on the west by a 25° east-dipping fault which three wells have encountered. These wells start in the Eocene and are completed either above or below the fault in beds of the same age. The initial production from each of these wells was less than 100 barrels per day and the oil varied in gravity from 19.6° to 22° A.P.I. The structure is a small Tertiary prospect since no closure was indicated in the Cretaceous by seismic sur-

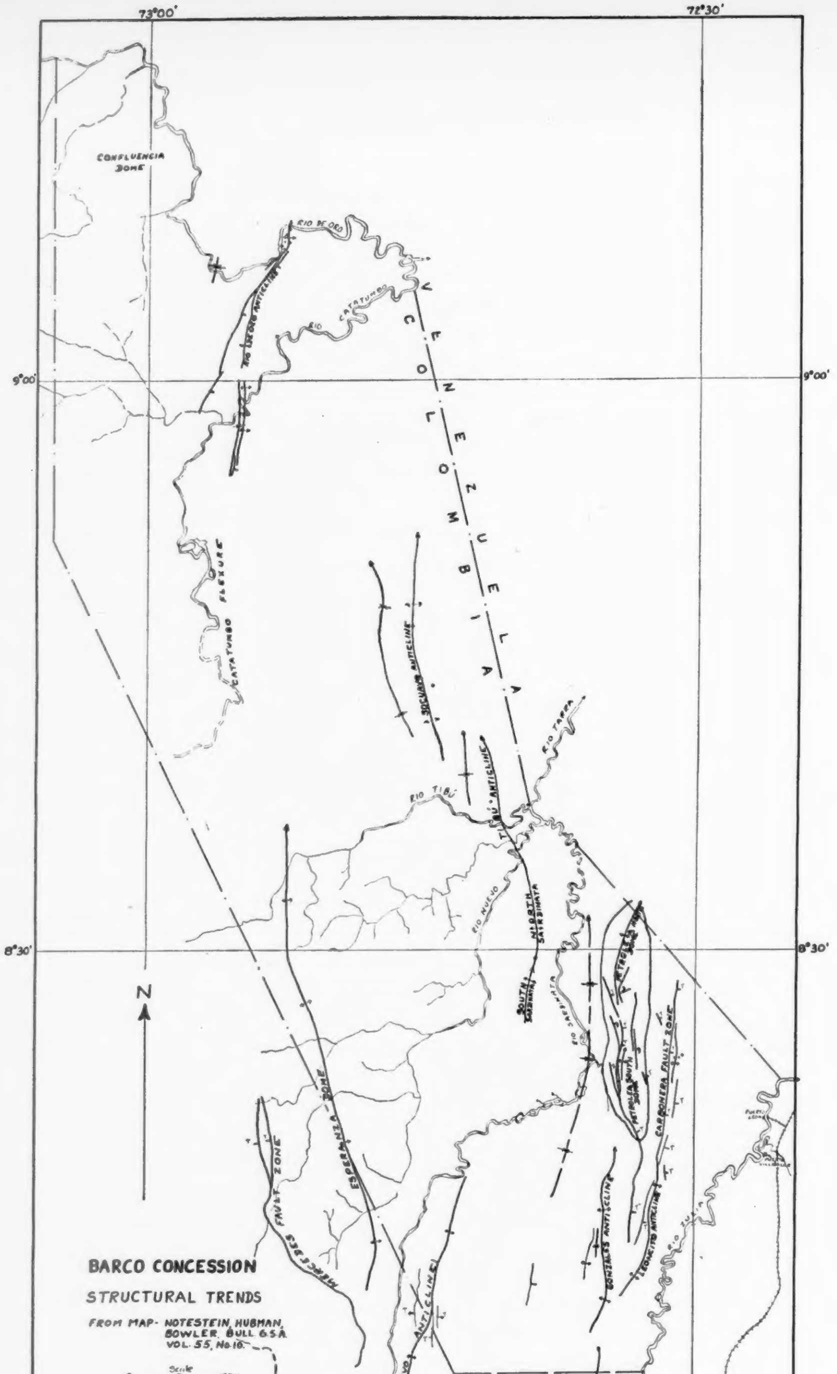


FIG. 29.—Map showing location of principal structures of Barco Concession, Colombia. (From Notestein, Hubman, and Bowler, 1944.)

veys. The total production to December 31, 1942, was reported to be 81,772 barrels.

In the foothill region of the eastern Sierra de Perijá, along the western margin of the Barco Concession, is a zone of folding and faulting to which the name Foothill folds has been given. Six structures have been recognized in this area (Fig. 29). The southernmost structure known as the Cuervo anticline has not been tested. A small closure is reported in the Tertiary but the Cretaceous is possibly not closed. The surface crest is cut by a fault whose plane dips 30°–35° W. The Esperanza anticline, a broad asymmetrical dome with little faulting has the Upper Cretaceous eroded and exposed. The only prospective productive formations are in the Lower Cretaceous and these have not been tested. The Mercedes fault zone is a complex system of west-dipping faults which lie outside the concession. Very little is reported to be known about the Catatumbo flexure which is caused by the uptilting of Tertiary sandstones probably due to faulting. North of the Catatumbo flexure and in the northern part of the concession lies the Río de Oro anticline. It is a long, narrow, faulted, highly asymmetric anticline extending from the Río Catatumbo to the Río de Oro and thence about 12 miles into Venezuela. The east flank of this structure is very steep while the west flank has a gentle dip. Two structural highs are reported on this anticline and beds of the lower Eocene (Barco) are exposed in both highs. Gas and oil seeps are common. Three wells have been drilled on the south high, the first completed in 1920 produced a small amount of oil from the lower Eocene (Barco) but was cased off and later abandoned in the uppermost Cretaceous (Catatumbo). When opened later it flowed fresh water and a small amount of oil. The other two wells were drilled into the upper part of the Uribante formation without finding oil but the Tibú member was not tested. Ten wells have been drilled on the north high of the Río de Oro anticline to an average depth of 1,410 feet. Three producing zones are recorded in the uppermost Cretaceous, the sands of which are reported to be very tight, fine-grained, and fractured. Producing thickness of these sands varies from 10 to 38 feet and the productive area is about 420 acres. The average daily production is reported to be 260 barrels per day per well on a $\frac{1}{4}$-inch choke with a gas-oil ratio of 340 to 1. The gravity of the oil ranges from 32° to 40° A.P.I. The Lower Cretaceous of the north high has not been tested. The Confluence dome, the northmost structure of the Foothills folds, located approximately 9 miles northwest of the Río de Oro camp is reported to be a low domal uplift on which the Lower Cretaceous (Uribante) is exposed. It is thought to be of no economic importance.

West of the Petrolea-Tarra anticlinorium lies the Sardinata depression and in it is located a line of folding extending a reported distance of at least 36 miles. Three important folds known as the Sardinata, Tibú, and Socuavó anticlines are located in this structural depression (Fig. 29).

The Sardinata anticline has two highs known as North Sardinata and South Sardinata. Seismic surveys report an asymmetric anticline with gently dipping

flanks and no major faulting. No oil or gas seeps have been reported on the structure. Both highs have been tested but no commercial production has been obtained from either the Tertiary or Upper Cretaceous. The lower Cretaceous has not been tested on either high.

The Tibú anticline is considered to be the northern continuation of the Sardinata structure. It is a slightly asymmetric fold with a reported average dip of 15° on the west flank and 6° on the east flank. Beds belonging to the Carbonera formation (Oligocene) crop out on the crest of the fold and three small seeps are reported. Seismic data reveal a closure on the La Luna limestone of 1,148 feet comprising 15,000 acres. Of the three original wells in the field, well No. 1 was completed in the Barco sand of the basal Eocene, with an initial production of 17 barrels per day of 31.2° A.P.I. oil; well No. 3 was also completed in the Barco sand with an initial production of 179 barrels of 22.5° A.P.I. oil and 51 barrels of fresh water; well No. 2-A was drilled 6 feet into the basement rocks at 9,227 feet and completed as a producer in the Tibú member of the Uribante formation of the Lower Cretaceous. The initial production was 430 barrels of 54.8° A.P.I. oil on a ¼-inch choke, with a tubing pressure of 2,900 pounds per square inch and a casing pressure of 3,140 pounds per square inch and a gas-oil ratio of 5,290. Drilling for Tertiary production was concentrated in this area during 1944. The wells drilled to an average depth of 4,000–5,000 feet and had initial production of about 250 barrels of 32° A.P.I. oil on ¼-inch chokes (*Oil and Gas Journal*, December 30, 1944). Oil from the Tibú field is being sent through the Sagoc pipe line to the Caribbean coast at Covenas (Fig. 16).

The Socuavó anticline is northwest of the Tibú structure and is reported to have a common closure contour on the La Luna horizon. Within a closure of 820 feet on the seismic La Luna horizon, there is a reported area of 12,000 acres. The structure is an asymmetric anticline with a steep west flank which is probably faulted and a rather gentle east limb. Beds belonging to the upper Carbonera formation of Oligocene age crop out on the crest of the structure. The first well on the Socuavó structure encountered the basement complex at 9,781 feet and was completed as a producer in the upper portion of the Uribante formation with an initial production of 136 barrels of 49.7° A.P.I. oil through a ¼-inch choke with a flowing pressure of 1,000 pounds per square inch on the tubing and 1,300 pounds on the casing. The gas-oil ratio was reported to be 9,547. The second well was completed as a Tertiary test in the basal Barco sands with an initial production of 197 barrels of 34.7° A.P.I. oil. The upper Barco sands revealed oil and some fresh water on drill-stem tests. Crude oil from the Socuavó field is piped into the main Sagoc line.

The production from the Barco Concession is pumped from the field to the port of Covenas on the Gulf of Morrosquillo, a distance of 263 miles, through a 12-inch welded steel line. The line crosses the Sierra de Perijá at a point 5,286 feet above sea-level, then traverses the valley of the Río Magdalena to Covenas. There are four pump stations and one relief station along the line whose present

capacity is rated at 25,000 barrels per day but whose potential capacity is 70,000 barrels. There is a reported storage capacity of 1,234,578 barrels of which 331,578 barrels is located at Petrolea and 903,000 barrels at Coveñas. The first oil was shipped from the ocean terminal on October 21, 1939. A 500-barrel refinery capable of supplying the local needs is located at Petrolea.

NORTH COAST AREA

The section of Colombia known as the North Coast area includes the coastal section adjacent to the Caribbean Sea, the Río Sinú Valley, the valley of the Río Magdalena as far south as El Banco, and the valley of the Río Cesar and its tributaries (Fig. 15). In general, the province is located in the departments of Atlántico, Bolívar, and Magdalena.

This is a region of well developed marine Tertiary rocks. The Eocene is widespread in the Sinú Valley nearly to its headwaters, in the ranges west of the Río Sinú, and along the coast. It is also known in the valleys of the Río San Jorge and Río Cesár (Anderson, 1926). Clays, sandy shales, and limestones called the Poso series by Anderson (1929) are reported by him to be rather widespread and to be of probable Oligocene age. This series is recognized by Anderson in the valley of the Río Sinú, along the coast north of Lorica, and in the region near the town of Turbaco. Recent drilling east of the lower Magdalena Valley indicates that the Oligocene is doubtless present in the subsurface. Shales, sandy shales, and sandstones of Miocene age are according to Anderson (1926) also widespread in the northern part of Colombia. They occur along the north coast from the Gulf of Urabá to Ríohacha, in the valley of the Río Magdalena as far south as El Banco, and in the valleys of the Río Sinú, San Jorge, and Río Cesár. The Pliocene rocks are known to occur near the coast where they are represented by sandy shales, and sandstones with corals (Anderson, 1926).

Sharp, asymmetric anticlines with steep west flanks (45°–75°) and gentler east flanks (5°–30°) are important structural features of the North Coast area. A few gentle folds with dips of 1°–10° are also known. Both Anderson (1928) and Beck (1921) mention a very prominent structural feature known as the Bolívar fault which is traceable for more than 100 miles N. 30° E. from near Montería northward to Calamar. Paralleling this fault is the prominent Sincelejo anticline described by Beck (1921) as an asymmetric fold extending for nearly 100 miles from near San Andrés northward toward Calamar (Fig. 30). Beck has also described several other structures in this area. The Sapo fold near the town of Palmito is a very sharp asymmetric fold with dips on the west limb of 60°–75° while on the east flank the beds are inclined 35°–50°. A small dome with gentle dips known as the San Andrés dome is also reported near the town of San Andres. Beck refers to the Lorica structure near the town of Lorica as a symmetrical anticline with dips varying from 10° to 30°. Near the town of Montería there is another structure which Beck has called the Montería anticline. Anderson (1926) mentions long gentle folds involving Miocene rocks, one such fold extending from

Puerto Colombia southwestward toward Tubará, Usiacari, Repelón, and Arenal. Faulting is known at the north end of this fold where oil seeps and older Tertiary rocks are present. Drilling east of the lower reaches of the Río Magdalena has revealed subsurface structures, thus indicating that the structural trends common to the west wide of the river carry across to the area on the east. Oppenheim (1942b), in discussing the geology and structure of the department of Magdalena, points out that the Miocene sediments east of the Magdalena River and also in the valleys of the Cesár and Rancheria rivers have been affected by the late Tertiary orogeny. Anticlinal and synclinal folds are present in these areas. Reymond (1942) has also noted gentle folds in the Tertiary rocks of the departments of Atlántico and Magdalena. The axes of these folds are oriented in northeast and southwest.

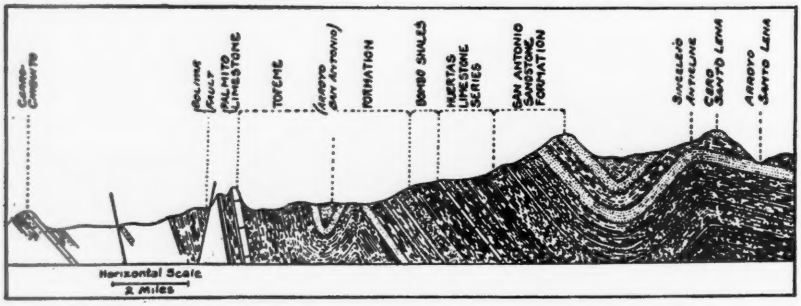


FIG. 30.—Cross section by Beck showing character of Sincelejo anticline and Bolívar fault, Department of Bolívar, Colombia.

Wheeler (1934) has presented a table which reveals that prior to January, 1934, 26 wells have been drilled in the departments of Atlántico and Bolívar exclusive of the Río Sinú area. Of these, 6 wells were under 1,000 feet, 6 were between 1,000 and 2,000 feet, 2 were between 2,000 and 3,000 feet, 8 were between 3,000 and 4,000 feet, and 4 were between 4,000 and 5,000 feet. In the Río Sinú area, 6 wells have been drilled, one of which was under 1,000 feet and 5 were between 3,000 and 4,000 feet. Washburne and White (1923) give detailed descriptions of many of these wells, indicating that some were located on well defined structures, others were poorly located, but that in almost every instance encouraging shows of both oil and gas were encountered. Of particular interest are two wells located about 6 miles southwest of Puerto Colombia near the town of Perdices. Peridices No. 6 reported showings of oil and gas at various horizons, and in a sandstone at 2,443–2,446 feet 3,000,000 cubic feet of gas was reported. Perdices No. 1 flowed naturally from broken shale and sand at 745–754 feet and on the pump was reported to have made 140 barrels of approximately 40° A.P.I. oil in 7 hours.

In the coastal area in general, surface evidences of petroleum are abundant, consisting of large active seeps of petroleum, gas, and mud volcanoes, associated with folded and fractured zones. Drilling on well defined structures hold some of the best possibilities of opening new fields.

Up to 1934 drilling was carried on in six areas as follows: the Río Sinú Valley, the Puerto Colombia area northeast of Turbará, the Turbaco area, in the vicinity of Zambrano, near El Carmen, and in the vicinity of San Jacinto. Recent operations include the drilling of a well in the Río Sinú Valley on the Floresanto tract by the Socony-Vacuum Oil Company and operations east of the Río Magdalena in the Río Cesár Valley and its tributaries. In the latter region, the Shell Oil Company has brought in its El Dificil No. 1 wihch was drilled into the Sierra Nevada granite at the depth of 5,950 feet. Due to high gas pressures, only a small portion of several hundred feet of Oligocene limestone were tested, yielding initially approximately 700,000 cubic feet of gas and 54 barrels of 46° A.P.I. paraffine base oil (E. Ospino-Racines, 1943). The Richmond Petroleum Company drilled two dry El Retiro wells south of the Shell's tests at El Dificil and El Brillante and are reported to have surrendered their concession. The Richmond Petroleum Company, The Texas Company, and the Socony-Vacuum are reported ready to drill exploratory tests in the region south of the Bay of Salamanca and north of the Shell's San Angel property (*Oil and Gas Journal*, December 11, 1944). At present the North Coast Area is undergoing systematic exploration by both surface geological studies and geophysical surveys. New fields in this region would be strategically located due to their proximity to the Caribbean coast.

LLANOS AREA

One of the potentially richest oil provinces of Colombia is located in the "llanos" southeast and east of the Cordillera Oriental (Figs. 16 and 17). It has been estimated that this region contains about 50 per cent of the prospective oil land of the country (E. Ospino-Racines, 1943).

Geologically, Oppenheim (1942) refers to three divisions of the llanos, first the front ranges of the Cordillera Oriental, second the llanos proper, and third the eastern margin which forms the western edge of the Guayana shield. The old basement of igneous and metamorphic rocks is known to crop out in the Macarena and also south of San Jose del Guaviare (Trumpy, 1943), thus further dividing the llanos into a northern and a southern part (Oppenheim, 1942) (Fig. 15). Pre-Cambrian rocks are also shown as cropping out along the Río Caquetá in the south-central part of the llanos (Mapa Geológico, 1944). Along the east front of the Cordillera Oriental rocks of all ages from pre-Paleozoic to Pleistocene are represented. According to Oppenheim, the Cretaceous did not cover the Macarena and it was not until the Lower Tertiary that this region was inundated. The geological map of Colombia shows Cretaceous rocks cropping out in numerous localities in the south-central and eastern portions of the llanos. The Tertiary deposits thicken both north and south of the Macarena. The central portion of the

llanos is covered, according to Oppenheim, by gravel and clay of Recent age. The eastern extent of the Cretaceous and Tertiary rocks is not known but they probably underlie much of the central llanos.

Faulting is pronounced along the foothills of the Cordillera Oriental. Oppenheim speaks of faults with slight hade which locally appear to be reversed faults and overthrusts (Oppenheim, 1942). Stutzer (1934h) records both faulting and anticlinal structures in the region of Gachalá. The principal uplift of this portion of the Cordillera Oriental began after the beginning of the Eocene and probably continued with interruptions into the Pliocene. Pronounced structures therefore should be expected along the entire eastern face of the Cordillera Oriental and should extend out into the central portion of the llanos, becoming gentler toward the east.

Both source rocks and reservoir beds of petroleum are present in the llanos area. The Lower and Middle Cretaceous would be classed as potential source rocks and any sand in the Upper Cretaceous and the Tertiary if found on suitable structures would serve as a reservoir. It is not known how far the potential Cretaceous source beds extend eastward and only drilling will reveal this fact.

Seepages of petroleum are recorded by Stutzer (1934h) from near Medina and by Oppenheim (1942) in various places along the foothills of the Cordillera Oriental. Both geological and geophysical parties have been active in the llanos area and numerous leases have been acquired.

During 1944, the Shell Oil Company drilled a well on the San Martin tract which was abandoned as a producer of fresh water (*Oil Weekly*, January 1, 1945). A second well is planned for the same tract. According to a concession agreement, the Richmond Petroleum Company was to have spudded in its wildcat on the San José tract by December 26, 1944 (E. Ospino-Racines, 1943). If geophysical surveys are successful in locating suitable structures in the central llanos area, then this region might be more attractive than the foothills area where the folding is more intense and the reservoir beds tighter. The central llanos area of Colombia might be comparable from a potential accumulation standpoint with the Venezuelan fields of the southern parts of the states of Anzoategui and Monagas.

RIO ATRATO VALLEY

The Río Atrato flows northward into the Gulf of Urabá through what was in Tertiary time the northern part of the Bolívar geosyncline (Fig. 15). Very little is known about this area and the only detailed work is that of E. Hubach (1930). According to this author, the valley of the Río Atrato is intensely humid and tropical and has a long rainy season lasting from April through December. In the dry season from December to April there is very little rainfall and the streams dry up. Malaria is very bad throughout the entire region. Travel is very difficult because of the lack of roads. Large rivers and tributaries may be navigated by launches and canoes.

According to Hubach the northern part of the Río Atrato Valley is largely

covered by Pleistocene and Recent materials. The geologic section as established by Hubach and based entirely on lithology is as follows.

Recent—Products of erosion from the mountains. Muddy sediments in places. Plant remains. Up to 200 meters in thickness in the Río Tasidó. Unconformity.

Upper Tertiary—Piso del Cuchillo-Piso del Pacífico

Coarse sands, gravels, and compact at times carbonaceous shales. Fossils of the specie Conus reported at the base. About 300 meters thick. Strong unconformity at base. Same lithology and marine fossils on Pacific coast.

Piso Currulao—Much like the underlying formation and hard to separate. Contains coal pebbles from underlying beds. About 1,200 meters thick with possible unconformity at base.

Lower Tertiary—Piso Tacanales

Rubble at base, sands, fossiliferous shales, and coal beds. About 1,000 meters thick with possible unconformity at base.

Piso Nuguiales—Conglomerate. Pebbles of quartzite, porphyrite, gabbro. Gray shale, sand, marine shells. About 1,000 meters thick with strong unconformity at base.

Cretaceous (?)—*Piso del Río Verde*

Quartzites and compact shales. Detrital carbonaceous matter. Possibly some *Inocerami* remains. About 1,000 meters thick.

Piso Mequerá—Alternating thick to thin gray shales and quartzitic sandstones. Reported ammonite remains. Thickness not determined.

Transition rocks—Gabbros, shales, carbonaceous sandstone. Age not definite. In Cordilleras Occidental and de la Costa.

Basement—Pre-Mesozoic, metamorphics. Gneisses and igneous.

Hubach's structural studies were concentrated in the Cordón de Abibe, the divide between the Río Sinú and the Río Atrato valleys. Here Tertiary rocks crop out in anticlinal and synclinal structures, many of which are highly faulted. The outcropping Tertiary rocks are believed to carry under the débris-filled valley of the Río Atrato. Manifestations of both petroleum and gas emanating from fractures and exposures in the crest of anticlines are reported by Hubach from the Cordón de Abibe. The seeps are in the Tacanales formation and the petroleum is reported to be paraffine in base by Hubach (page 116). No seeps are reported from the valley of the Río Atrato or Río León although Hubach believes that potential petroleum-bearing structures may be buried under the débris of the Río León from at least Pavarandocito at the headwaters at the Río Sucio northward to the Gulf of Urabá. Although Cretaceous rocks were reported by Hubach from the valley of the Río Atrato and are shown on the geological map of Colombia, Olsson suggests further study of this section before a definite Cretaceous age is assigned to it. The entire northern portion of the valley of the Río Atrato is classified as National Reserve (map, E. Ospino-Racines, 1943). The general area is probably one of the least attractive of the Colombian provinces.

SOUTHWESTERN COASTAL AREA

Olsson (1940, p. 252) has pointed out that the low southwestern coast of Colombia between Buenaventura and the Ecuadorian border is covered by alluvium and stream gravels and that Tertiary outcrops are rare (Fig. 15). They are, however, recorded from the low hills north of Tumaco and along the Río Patía near the mountains. According to Olsson, the southwestern coastal plain near the Ecuadorian border is covered by thick deposits of volcanic ash and conglomerates. If geological structures suitable for accumulation of petroleum are

present, they are buried beneath this covering of volcanic débris and stream alluvium and must be located by geophysical methods.

E. Grosse (1935b) made a geological reconnaissance from Popayan to Tumaco by the way of the gorge of the Río Patía. From the gorge of the Río Patía he describes graphitic and sericitic phyllites and interbedded quartzites, which are assigned to the pre-Cambrian. Gray slates weathering yellow are called the Chita beds and are referred to the Paleozoic. On the basis of lithologic similarity with the sections in the Río Caquetá region, Grosse assigns the very extensive development of basic effusive rocks and tuffs to the Cretaceous. Associated with these igneous rocks are siliceous shales, gray shales, some coarse sandstones and black bituminous shales from near Córdoba north of the Ecuadorian border.

The Tertiary of the Patía gorge is divided by Grosse into the following.

Quaternary—Volcanics
Neo-Tertiary—Andesitic tuffs and agglomerates, sands and shales. Probable discordance at base
Medio-Tertiary—(Honda)
  Upper—Tuffaceous sediments
  Lower—Conglomerates, sandstones, shales. Probable small discordance at base
Eo-Tertiary (Guaduas of Hettner)—Sands, shales, and coal beds. Fossils, sea urchin, gastropods, and lamellibranchs, found in Lower and Middle Tertiary

The beds of the Patía gorge are according to Grosse intensely folded and thrust faulted. Folding in the Cretaceous is independent of that of the Tertiary and thrusting is from the east. Two periods of Tertiary folding were noted, one at the close of the Middle Tertiary and the other at the close of the Upper Tertiary. Each, according to Grosse is independent of the other. No structures were noted in the coastal plain region of southwest Colombia on account of the covering of Quarternary volcanics.

Evidences of petroleum in both the Cretaceous and Tertiary are very small. Grosse reports a block of bituminous shale containing asphalt in thin sand seams and fissures near the town of Córdoba. Seeps in the Patía gorge were reported to Grosse but were not seen by him. Small showings in sands of the Lower Tertiary are reported by Grosse from 11 kilometers southwest of the town of Mercederes, in the Quebrada Playa. Royo y Gomez (1942a and 1942b) reports finding no source rocks of petroleum in either the gorge of the Río Patía or in the gorge of the Río Mayo.

The presence or absence of suitable structures in the southwestern coastal plain would have to be proved by geophysical methods or by drilling. The general character of the Cretaceous sediments in the Patía gorge where they are associated with basic extrusives does not argue in their favor as far as a possible source rock is concerned. If the lower and middle Tertiary beds are marine and are buried along the southwest coast, then there is a possibility that oil could have been derived from these horizons. The region has been recently visited by a geophysical party.

Origin of Colombian Petroleum

General.—There are two views concerning the origin of the Colombia oil. The first, suggested by Stutzer (1934d), advocates that the Villeta or Lower Creta-

ceous is the source of the petroleum of the middle and upper Magdalena Valley. F. M. Anderson (1926) challenged this idea and postulated an Eocene source for all of the Colombian oil. Etherington (1944) has recently reported free light-green oil from ammonites of the *Oxytropidoceras* zone of the middle Albian. Information which has accumulated since Anderson's original work therefore strongly suggests that not one but several formations have yielded the bulk of the Colombian petroleum.

Source beds.—In the northern coastal area Anderson points out that the Eocene contains marine beds with intercalated coal-bearing strata and where surface evidences of petroleum are present the Eocene is either exposed or very near the surface on structures suitable for accumulation. He admits that the Miocene is of marine origin but stresses the lack of strata "of organic nature" which he thinks would be a possible source of petroleum. Recent drilling in the Río Cesár area has resulted in the discovery of high-gravity, paraffine base oil in what has been called upper Oligocene limestone (E. Ospino-Racines, 1943). The marine character of the Tertiary section of the northern coastal region would therefore suggest that no one formation acts as the source rock.

The Tertiary sediments of the middle and upper Magdalena Valley were deposited in a non-marine environment and are considered to be deltaic in origin. Visible carbonaceous matter is practically absent and the shales of the region are oxidized and possess gray, purple, and brown colors. With the exception of the basal portion of the Lisama formation which contains minor amounts of carbonaceous shale and a few thin coal beds, no shale has been seen that could adequately be referred to as a source bed. On the other hand, the highly carbonaceous shales and bituminous limestones of the Cretaceous possess all the attributes of source rocks.

The bulk of the production of the Barco area comes from the Cretaceous. Both the La Luna and the Cogollo limestones are rich in organic remains and are considered to be source rocks (Notestein *et al.*, 1944). There is a possibility that the oil of the Eocene Barco sands is indigenous to that formation but a lower source is not discounted (Notestein, 1944). In this instance the oil is reported to be heavier than the Cretaceous oil but possesses the same dark brown to black color.

Possible origin of Colombian petroleum.—It is important to note that both paraffine and asphalt base crude is produced in Colombia, the former possessing a high gravity and the latter a moderately low gravity. The question to be considered is whether or not these two types are derived from the same source.

In discussing the California oils, Taff (1934) points out that those formations possessing animal organisms produce a naphthene oil which contains "little or no tar residue with more or less wax or paraffin" while the formations containing diatom or plant remains in abundance produce naphthene oil with a tar base and generally free of wax or paraffine. Brooks (1938) reports that "all asphalts examined and all asphaltic petroleums contain chlorophyll porphyrins" thus suggesting that asphaltic oils are derived from source beds containing plant remains. Brooks

refers to Treibs' conclusion that "the clear asphalt-free oils had lost their porphyrin content by adsorption during filtration through absorbent material." Treibs also considers oils of medium viscosity and considerable asphalt content to represent a more original oil while the lighter-colored, thinner oils are classed as "natural raffinates." Barton (1934), in discussing the history of the Gulf Coast crude oil, postulates that all crude petroleum starts as a heavy oil and that temperature, pressure, and other factors such as depth, time, and catalysts act on the oil to change it from a heavy crude, through a progressively lighter series of oils, thence into paraffine-base oils.

In applying the foregoing postulates to the Colombia oils, we must first search for a formation which was deposited in an environment favorable for organic life and which possessed anerobic conditions during sedimentation. If the theories of Barton and Treibs that all petroleum was originally heavy and asphaltic are accepted and if the observations of Brooks that asphaltic oils are derived from plant remains can be applied to the Colombian oils, then the source beds of the Colombia asphaltic oils are more likely to be found in the Upper Cretaceous Umir and lower Eocene Lisama formations. The Umir contains coal beds and is rich in organic remains while the Lisama formation is slightly less so. It is the writer's opinion that the asphaltic crude of the middle Magdalena Valley in the vicinity of the De Mares Concession is not indigenous to the upper Eocene and Oligocene because of the generally oxidized character of the shales as observed in the subsurface, a condition which does not favor the retention of organic matter at the time of deposition.

The Cretaceous oils of the Barco area have had a different history than the Tertiary oils of the Magdalena Valley. They were doubtless derived from the Lower Cretaceous limestones and shales which were probably more affected by temperature and pressure changes than were the postulated Upper Cretaceous and lower Eocene source beds of the Magdalena Valley. The Cretaceous oils of the Barco are high gravity and paraffine-base crudes. Drilling near Barrancabermeja on the De Mares Concession has proved the presence of an unconformity between the Tertiary and the Cretaceous. In one place solid hydrocarbon was encountered near the unconformity and within the Cretaceous a small showing of light, clear oil was encountered. This oil was distinctly different in its physical aspects from that in the overlying Tertiary sands. The Cretaceous therefore in this particular area obviously did not supply the oil to the overlying Tertiary reservoirs.

The Tertiary sediments thicken east, south, and possibly north from the La Cira and Infantas fields (Fig. 13). On the outcrop the shales are highly oxidized and do not appear carbonaceous. Trask (1938) has pointed out that the average quantity of organic matter in recent sediments is about 2.5 per cent by weight and in near-shore marine sediments it ranges from 1 to 7 per cent. The average organic content of several thousand sediments ranging in age from Cambrian to Pliocene in the United States is according to Trask 1.5 per cent. These figures indicate that, in order to be a source bed, sediments do not necessarily

have to be rich in organic matter. On this basis, it appears that at least a portion of the very thick Tertiary shales, south and east and possibly north from the La Cira region, which were deposited under non-marine, deltaic conditions, might have contained enough carbonaceous matter to produce the petroleum of the Eocene and Oligocene, a fact which can not be dismissed altogether without further investigation.

The location of commercial deposits of petroleum in the middle Magdalena Valley is interesting when considered from the standpoint of regional structure. At present, the producing structures are located near the latitude of Barrancabermeja and immediately north of this town. Drilling to about 25 miles southeast of Puerto Berrío on well developed structures has failed to reveal commercial deposits of petroleum. Two previously mentioned wells drilled by the Sociedad Nacional del Carare stopped in the basal Tertiary sands and were dry holes. Drilling on the Mugrosa, Colorado, and San Luis faulted anticlines of the De Mares Concession (Fig. 17) revealed small but non-commercial deposits and the structures were abandoned. Drilling which penetrated the entire Tertiary section north of the Sogamoso River also failed to discover commercial production.

The presence of an unconformity between the Tertiary and Cretaceous in the La Cira and Infantas fields indicates that folding, probably faulting, and erosion took place at the close of the Cretaceous in this part of ths Magdalena Valley. East of the La Cira-Infantas area in the foothills of the Cordillera Oriental, there appears to be a gradual transition from the Cretaceous Umir into the Eocene Lisama formation. This is also true in the Aguas Claras area north of the Sogamoso River. There was therefore a regional high located in the La Cira-Infantas area at the close of the Cretaceous. The presence of solid hydrocarbon matter encountered near the unconformity indicates that oil had been generated in the Cretaceous black shales and at least a portion had escaped during the period of erosion and before the basal Tertiary was deposited.

The thin Tertiary section on both the La Cira and Infantas structures suggests that the Tertiary beds were being deposited over the regional high which continued to be elevated during the deposition of the Tertiary. The petroleum which most likely originated in the Umir or Lisama formation or both found its way into the reservoir beds of the Eocene and Oligocene probably after the orogeny that affected the Lisama formation. This orogeny was largely restricted to the area between the Sogamoso and Opon rivers (Wheeler, 1935, p. 29). The Toro formation which rests on either the Lisama or older formations indicates by its composition that after the period of uplift and erosion there was a period of differential sinking again largely restricted to the area between the Sogamoso and Opon rivers. The character of the Toro formation indicates that sinking was not profound and was followed by a gradual uplift. Once the petroleum entered the Tertiary sands, it migrated into the regional high area before the profound revolution of the Miocene-Pliocene period. The present Tertiary structures of the Magdalena Valley are the result of the folding and faulting which took place at the close of the Miocene. The orogeny of this period served to isolate the

petroleum deposits and their associated waters on the structures where they are now found. The gravity of the Eocene oil of the De Mares concession which varies from 20° to 35° A.P.I. and its asphaltic character suggest, in light of Barton's postulates, that it had not migrated very far from its source. The distribution of the oil on the De Mares structures indicates an increase in gravity and quality with depth.

Petroleum Development

The equitable petroleum laws under which the companies operate have been summarized by Jorge Gartner (1939) and E. Ospino-Racines (1939). All aspects of petroleum concessions are covered by Law 37 of 1931 and Law 160 of 1936. The following are the principal features of the Colombian petroleum legislation.

1. Petroleum contracts are made to cover up to 50,000 hectares per person (123,500 acres) in all parts of the country except the llanos area.
2. Contracts in the llanos area are now made up to 100,000 hectares (247,000 acres) per person.
3. Transfers permitted to the same person up to 50,000 hectares in the first zone.
4. Period of exploitation is 30 years which may be extended 10 years.
5. Period of exploration is 3 years and may be extended 6 years.
6. Period of exploitation commences at the termination of the exploration period.
7. Payments to the government during the exploration period varies from 10 centavos to 2.00 pesos per hectare per year.
8. Royalties during exploitation vary from 11 to 2 per cent on gross production depending on whether the distance from the maritime port of shipment is between 0 and 900 kilometers or more. Royalties may be taken by the Government in kind at the center of the gathering system plus an amount equivalent to the cost of transportation from the center of the gathering system to the port of shipment.
9. Processing of gases pays a royalty of 1/30 of the amount of natural gasoline extracted or a payment of 5 centavos per 10,000 cubic feet when sold.
10. Contracts for concessions carry the right to construct pipe lines for the concessions and no taxes or special royalties are levied on these lines.
11. Non-exploiting companies may construct pipe lines. The tax is 2½ per cent of the value of the number of barrels transported by the prevailing tariff for the pipe line which, according to E. Ospino-Racines is a maximum of 40 centavos for the first 100 kilometers and 5 centavos for each additional 100 kilometers up to 800 kilometers. Pipe-line tariffs are to be determined through mutual agreement between the operators and the Government taking into account capital invested *et cetera.*
12. Refineries may be established free but the Colombian Government requires a permit to build within a 20-kilometer radius of certain maritime ports.
13. The petroleum industry is exempt from municipal or departmental and river taxes. There is no tax on the export of crude oil and no other special taxes.
14. There is an income tax on net profits.
15. Concessionaires must comply with the social laws in force in the country.
16. Contracts for petroleum land are granted the rights of eminent domain over private lands necessary for the benefit of the concession.
17. Government tax on oil from private lands varies from 7 to 0.5 per cent depending on whether the distance from maritime port to the field is between 0 and 900 kilometers or more. Clear title to private must be prior to October, 1873, to carry subsoil rights otherwise the Government controls the subsurface rights.

According to E. Ospino-Racines (1943) certain modifications to the petroleum law have been proposed to the Colombia Congress. These proposed changes are the following.

1. The reduction of the maximum acreage of a single concession from 50,000 to 25,000 hectares (123,500 acres to 61,700 acres) and from 100,000 to 60,000 hectares (247,000 to 148,000 acres) in the llanos.
2. Royalties to be increased 2 per cent payable at port and 1 per cent increase for the llanos area.
3. Ceiling on the number of concessions held by one operator which is now two (2) to be lifted.
4. Provision dealing with private oil—title, recognition, *et cetera.*

According to E. Ospino-Racines (1943) the Colombian Government had accepted 75 applications for concessions encompassing 9,270,000 acres since the passage of the petroleum law in 1931 to June, 1943. Of the foregoing, 24 concessions totaling 2,160,000 acres were under contract. Between June and December, 1943, 51 additional contracts were filed for an additional 6,175,000 acres. The 126 concessions covering a total of approximately 15,550,000 acres has been estimated to represent roughly 30 per cent of the prospective oil land of the country. In addition to the applications filed with the Government, are 1,735,000 acres of private oil land held under lease. Approximately half of the leased private land is recognized as being of firm title and the balance with a tentative decision in its favor. Estimated petroleum reserves of Colombia vary from 400,000,000 barrels to 500,000,000 barrels. The large leasing program which dates from 1931 to the present indicates that Colombia is to undergo an extensive wildcatting program when conditions permit.

The following table gives a summary of production in Colombia by fields to the end of 1941, the last year that complete reliable figures are available. Cu-

COLOMBIAN PRODUCTION

Name of Field	*Year of Discovery*	*Production in Barrels*		*Estimated Production in Thousands of Barrels*[d]		
		Total Production to End of 1941	*Total Production to End of 1942*	*1942*	*1943*	*1944*
DeMares Concession[a]				10,590	13,750	23,500
(Tropical Oil Co.)						
Infantas	1918	130,810,695	X			
La Cira	1926	161,164,928	X			
San Luis	1925	7,996	7,996			
Colorado	1927	1,901	1,901			
Mugrosa	1928	69,838	69,838			
Total		292,055,358	—			
Barco Concession[b]						
(Colombian Petroleum Co.)						
Petrolea	1933	9,793,663	10,896,617[c]			
Río de Oro	1937	64,708	64,708			
Carbonera	1938	64,665	81,772			
Tres Bocas	1940	5,056	20,087			
Sardinata Sur	1941	294	294			
Socuavó	1942	—	39,585			
Total		9,928,386	11,103,063			
Yondo Concession						
(Shell Oil Co.)						
Casabe	1941	5,598	X			
Total Colombia		301,989,342	—			

COLOMBIAN RESERVES

Estimated Reserves in Barrels[e] *Maximum*	*Minimum*	*Percentage of World Reserves*
500,000,000	400,000,000	1

[a] Figures for DeMares Concession from O. C. Wheeler, *Trans. A.I.M.E.*, Petroleum Division (1941), and *Oil Weekly*, Vol. 106, No. 8 (July 27, 1942).
[b] Figures for Barco Concession from *Oil Weekly* (July 27, 1942).
[c] Figures for Barco Concession, 1942, from Notestein, Hubman, and Bowler, *Bull. Geol. Soc. America*, Vol. 55, No. 10 (October, 1944).
[d, e] Figures from *Oil Weekly*, Vol. 116, No. 2 (December 11, 1944).

mulative production by fields for the Barco Concession to the end of 1942 are available and have been included. Increased production in the Tres Bocas area of the Barco Concession, in the Casabe field of the Shell, and in the Cimitarra area of the Socony-Vacuum will greatly increase the yearly production over that prior to 1941. Colombia normally ranks eighth in world production and second to Venezuela in South America.

SELECTED BIBLIOGRAPHY

ANDERSON, F. M. (1926), "Original Source of Oil in Colombia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 10, pp. 382–404.

——— (1927), "Non-Marine Tertiary Deposits of Colombia," *Bull. Geol. Soc. America*, Vol. 38, pp. 591–644.

——— (1928), "Notes on Lower Tertiary Deposits of Colombia and Their Molluscan and Foraminiferal Fauna," *Proc. California Acad. Sci.*, 4th Ser., Vol. 17, No. 1, pp. 1–29.

——— (1929), "Marine Miocene and Related Deposits of North Colombia," *ibid.*, Vol. 18, No. 4, pp. 73–213.

BARTON, DONALD C. (1934), "Natural History of the Gulf Coast Crude Oil," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol., pp. 109–55.

BECK, ELFRED (1921), "Geology and Oil Resources of Colombia; The Coastal Plain," *Econ. Geol.*, Vol. 16, pp. 457–73.

BROOKS, BENJAMIN T. (1938), "The Chemical and Geochemical Aspects of the Origin of Petroleum," *The Science of Petroleum*, Vol. I, pp. 46–53. London.

BUTLER, JOHN W. (1939), "Geology of Middle and Upper Magdalena Valley," *World Petroleum*, Vol. 10, No. 3, pp. 95–100.

——— (1942), "Geology of Honda District, Colombia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 26, No. 5, pp. 793–837.

CASTER, KENNETH E. (1940), "The Age and Relations of Colombian Devonian Strata," *Proc. 8th Amer. Sci. Cong., Washington*, Vol. IV, pp. 27–67.

CIZANCOURT, HENRY DE (1933), "Tectonic Structure of Northern Andes in Colombia and Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17, pp. 211–28.

CLEMENTS, THOMAS (1940), "The Bogotá Fault, Colombia, South America," *Jour. Geol.*, Vol. 48, pp. 660–69.

CODAZZI, R. LLERAS (1915), "Reseña geológica del departamento de Cundinamarca." *Proc. 2d Pan American Cong.*, Vol. 8, Sec. VII, pp. 351–62.

——— (1933), "Informe relativo a las regiones de Barzalosa y Guavinol, Cundinamarca," *Compilacion de los Estudios Geológicos Oficiales en Colombia 1917–1933*, Tomo I, pp. 265–71.

Compilacion de los Estudios Geológicos Oficiales en Colombia, Tomos I, II, III, IV, V. Ministerio de Industrias, Bogotá, Colombia.

DICKEY, P. A. (1941), "Pre-Cretaceous Sediments in Cordillera Oriental of Colombia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 25, No. 9, pp. 1789–95.

DIETRICH, W. O. (1935), "Zur Stratigraphie der kolumbianisher Ostkordillere," *Centralblatt für Min., Geol. und Paleon.*, pp. 74–82.

DUCE, J. T. (1935), Review of Stutzer and Scheibe, *Compilation of Official Geological Studies in Colombia, 1917–1933*, Vol. II (1935), *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 19, pp. 1560–61.

ERMISCH, KARL (1932), "Ein Profil durch den Chocó Westhang der West-Kordillere in Kolumbien, Südamerika," *Zeits. für Prak. Geol.*, Vol. 40, pp. 17–21.

——— (1934), "Die mittetertiäre Chuspas Stufe des Magdalenen Tales in Kolumbien," *Neues Jahr.*, B. Bd., Vol. 68-A, pp. 439–520.

ETHERINGTON, T. J. (1944), "Free Oil in Ammonites, Colombia, South America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 28, No. 6, pp. 875–76.

EUGSTER, HERMANN (1922), "Zur Geologie der Columbianischen Ostkordilleren," *Eclogae Geol. Helvetiae*, Vol. 17, pp. 251–66.

GARNER, A. H. (1927), "General Oil Geology of Colombia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 11, pp. 151–56.

GARTNER, JORGE (1939), "Equitable Colombian Oil Laws," *World Petroleum*, Vol. 10, No. 3, pp. 44–47.

GERTH, H. (1935), *Geologie Südamerikas*, pp. 1–389. Borntraeger, Berlin.

GREGORY, J. W. (1929), *The Structure of Asia*, pp. 163–68. London.

GROSSE, EMIL (1926), *El Terciario Carbonífero de Antioguia*. Berlin (1926).

——— (1931), "Acerca de la geología del Sur de Colombia," *Bol. de Minas y Petrol.*, Tomo IV, Numeros 23 y 24. Bogotá (1930).
——— (1935a), "Informe rendido al Ministerio de Industrias sobre un viaje al Huila y Alto Caquetá," *Compilacion de los Estudios Geológicos Oficiales en Colombia, 1917–1933*, Tomo III, pp. 31–137.
——— (1935b), "Informe rendido al Ministerio de Industrias sobre un viaje por la cuenca del Patía y el Departamento de Nariño," *ibid.*, pp. 139–231.
HARRISON, J. T. (1929), "The Magdalena Valley of Colombia, S.A.," *15th Internat. Geol. Cong., South Africa, Compte Rendu*, Vol. II, pp. 399–409.
HEDBERG, H. D. (1931), "Cretaceous Limestone as Petroleum Source Rock in Northwestern Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 15, pp. 229–46.
——— (1937), "Stratigraphy of the Río Querecual Section of Northeastern Venezuela," *Bull. Geol. Soc. America*, Vol. 48, pp. 1971–2024.
——— (1940), "Mesozoic Stratigraphy of Northern South America," *Proc. 8th Amer. Sci. Cong., Washington*, Vol. IV, pp. 195–227.
HETTNER, A. (1892), "Die Kordillere von Bogotá," *Petermann. Mitteil.*, Erganzungsheft 104, Vol. 22, pp. 1–131.
HUBACH, E. (1930), "Informe geológico de Urabá," *Boletin de Minas y Petroleo*, Tomo IV, Nos. 19 y 20, pp. 26–136.
——— (1931), "Exploración en la región de Apulo-San Antonio-Viotá," *ibid.*, Nos. 25–27, pp. 41–59.
HIGHTOWER, J. V. (1942), "Shell Opens Badly Needed Field for Colombia," *Oil Weekly*, Vol. 106, No. 8.
HUNTLEY, L. G., and MASON, SHIRLEY (1923), "Colombian Oilfields," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 68, pp. 1014–22.
IRISSARI, A. DE M. (1929c), "Tertic Geology of Colombia," *Pan.-Amer. Geol.*, Vol. 52, pp. 27–38.
——— (1929a), "Andean Basement Complex in Colombia," *ibid.*, pp. 125–28.
——— (1929b), "Physiography of Colombia," *ibid.*, pp. 195–200.
JAMES, PRESTON E. (1942), *Latin America.* The Odyssey Press, New York.
KARSTEN, HERMANN (1886), *Géologie de l'ancienne Colombie bolivarienne.* Berlin.
KEHRER, WILHELM (1936), "Versuch einer Gliederung der Kolumbianischen kreide im südosten von Bogotá," *Zentralblatt für Min. Geol. und Paleon.*, B, pp. 309–27.
——— (1939), "Zur geologie der südlichen zentral und ost-kordillere der Republik Kolombien," *Neues Jahrb. für Min. Geol. und Paleon.*, B. Bd. 80-B (1938). pp. 1–30.
Mapa Geológico General de la Republica de Colombia (1944). Scale 1:2,000,000, Bogotá.
NOTESTEIN, FRANK B.; HUBMAN, CARL W.; BOWLER, JAMES W. (1944), "Geology of the Barco Concession, Republic of Colombia, South America," *Bull. Geol. Soc. America*, Vol. 55, pp. 1165–1216.
OLSSON, A. A. (1932), "Contributions to the Tertiary Paleontology of Northern Peru. The Peruvian Miocene," *Bull. Amer. Paleon.*, Vol. 19, No. 68.
——— (1940), "Tertiary Deposits of Northwestern South America and Panamá," *Proc. 8th Amer. Sci. Cong., Washington*, Vol. IV, pp. 231–87.
——— (1940), "Some Tectonic Interpretations of the Geology of Northwestern South America," *ibid.*, pp. 401–16.
OPPENHEIM, VICTOR (1940), "Jurassic-Cretaceous (Girón) Beds in Colombia and Venezuela," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 9, pp. 1611–19.
——— (1942a), "Rasgos Geológicos de los 'Llanos' de Colombia Oriental," *Inst. del Museo de la Univ. Nac. de la Plata*, Tomo VII, No. 21, pp. 229–46.
——— (1942b), "Geología del Departamento del Magdalena," *Compilación de los Estudios Geológicas Oficiales en Colombia*, Tomo V, pp. 489–501.
OSPINO-RACINES, E. (1939), "Economic Aspects of Oilfield Exploitation in Colombia," *World Petroleum*, Vol. 10, No. 3, pp. 60–69.
——— (1943), "Colombian Discoveries Indicate Extensive Exploitation Program," *Oil and Gas Jour.*, Vol. 42, No. 34, pp. 104–08.
Oil and Gas Journal. Petroleum Publishing Company, Tulsa, Oklahoma. Various issues.
Oil Weekly. Gulf Publishing Company, Houston, Texas. Various issues.
PILSBRY, HENRY A., and OLSSON, AXEL A. (1935), "Tertiary Fresh Water Mollusks of the Magdalena Embayment, Colombia," *Proc. Acad. Nat. Sci. Philadelphia*, Vol. 87, pp. 1–21.
RENZ, H. H. (1940), "Stratigraphy of Northern South America, Trinidad, and Barbados," *Proc. 8th Amer. Sci. Cong., Washington*, Vol. IV, pp. 513–17.
REYMOND, EDOUARD (1942), "Informe sobre una misión geológica en los Departamientos del Magdalena y Atlántico," *Compilación de los Estudios Geológicos, Oficiales en Colombia*, Tomo V, pp. 417–60. Bogotá.
ROYO Y GOMEZ, JOSÉ (1942a), "Datos para la Geología económica de Nariño y Alto Putumayo," Compilación de los Estudios Geologicos Oficiales en Colombia, *ibid.*, pp. 53–180.

——— (1942b), "La cuenca del rio Mayo y su formación granatifera," *ibid.*, pp. 181–211.
——— (1942c), "Contribucion al conocimiento de la Geologia del valle superior del Magdalena (Departamento del Huila)," *ibid.*, pp. 261–326.
——— (1942d), "Fósiles devónicos de Floresta (Departamento de Boyacá)," *ibid.*, pp. 389–95.
——— (1942e), "Fósiles del Terciario marino del Norte de Colombia," *ibid.*, pp. 461–88.
RUTTEN, L. M. (1940), "General Tectonics of Colombia and Venezuela," *Proc. 8th Amer. Sci. Cong.*, Washington, Vol. IV, pp. 417–44.
SARMIENTO SOTO, ROBERTO (1942), "Geología económica de la region Paipa—Duitama—Santa Rosa de Viterbo, en el Departamento de Boyacá," *Compilación de los Estudios Geológicos Oficiales en Colombia*, Tomo V, pp. 1–51. Bogotá. This article contains a petrographic study by Roberto Sarmiento Soto and a paleontologic study by José Royo y Gómez.
SCHEIBE, ROBERT (1933), "Las relaciones entre los pisos de Honda, Gualanday, y Barzalosa," *ibid., 1917–1933*, Tomo I, pp. 63–65.
——— (1933b), "Geología del Sur de Antioquia," *ibid.*, pp. 97–167.
Science of Petroleum. Oxford University Press, London (1938).
SCHUCHERT, CHARLES (1935), *Historical Geology of the Antillean-Caribbean Region.* John Wiley and Sons, Inc., New York (1935).
SIEVERS, W. (1888), "Die Sierra Nevada de Santa Marta und die Sierra de Perijá," *Zeits. Gesell. f. Erdkunde zu Berlin*, Vol. 23, pp. 1–158.
STILLE, HANS (1907), *Geologische studien im gebiete des Río Magdalena.* Stuttgart.
——— (1938), "Estudios geológicos de la región del rio Magdalena. Traducidas por Jaime Bonilla Plata. Revisado por Julio de Mier Restrepo." *Compilación de los Estudios Geológicos Oficiales en Colombia, 1917–1933*, Tomo IV, pp. 125–82. Bogotá.
STUTZER, O. (1925, 1926a), "Beiträge zur geologie und mineralogie von Kolombien," *Neues Jahrb.*, Vol. 52-B, pp. 162–74 and Vol. 53-B, pp. 315–24.
——— (1934d), "Sobre la geología de la parte media del valle del Magdalena," *Compilación de los Estudios Geológicos Oficiales en Colombia, 1917–1933*, Tomo II, pp. 183–209.
——— (1934c), "Observaciones geológicas durante una doble travesía por la Cordillera Central de Colombia," *ibid.*, pp. 17–38.
——— (1927b), "Zur Geologie der Goajira-Halbinsel, Kolumbien," *Zeit. der Deutschen Geol. Gesell.*, Vol. 79, pp. 205–09.
——— (1934e), "Contribucion a la geología de la península de La Goajira," *Compilación de los Estudios Geológicos Oficiales en Colombia, 1917–1933*, Tomo II, pp. 211–43.
——— (1934f), "Acerca de la geología de la Cordillera Occidental entre Cali y Buenaventura," *ibid.*, pp. 39–52.
——— (1934g), "Contribución a la geología del foso del Cauca-Patía," *ibid.*, pp. 69–140.
——— (1934h), "Contribución a la geología de la Cordillera Oriental. Regiones cerca á Bogotá," *ibid.*, pp. 141–82. (Twelve separate articles.)
TAFF, JOSEPH A. (1934), "Physical Properties of Petroleum in California," *Problems of Petroleum Geology*, pp. 177–234.
TRASK, PARKER D. (1938), "Petroleum Source Beds," *Science of Petroleum*, Vol. I, pp. 42–45. London.
TRUMPY, D. (1943), "Pre-Cretaceous of Colombia," *Bull. Geol. Soc. America*, Vol. 54, pp. 1281–1304.
WASHBURNE, CHESTER W., and WHITE, K. D. (1923), "Oil Possibilities in Colombia," *Trans. Amer. Inst. Min. Met. Eng.*, Vol. 68, pp. 1023–31.
WEHRENFELS, A. (1926), "A Stratigraphic Section through the Tertiary of Toluviejo, Colombia," *Eclogae Geol. Helvetiae*, Vol. 20, pp. 79–83.
WEISKE, F. (1938), "Estudio sobre las condiciones geológicos de la hoya del Río Magdelena," *Compilación de los Estudios Geológicos Oficiales en Colombia, 1917–1933*, Tomo IV, pp. 15–124. Bogotá.
WHEELER, O. C. (1935), "Tertiary Stratigraphy of the Middle Magdalena Valley, Part III," *Proc. Acad. Nat. Sci. of Philadelphia*, Vol. 87, pp. 12–39.
——— (1934), "Petroleum Development in Colombia during 1933," *Trans. Amer. Inst. Min. Met. Eng.*, Petrol. Division, Vol. 107.
——— (1941), "Petroleum Development in Colombia during 1940," *Ibid.*, Vol. 142.
WHITE, K. D. (1917), "Oil Development in Colombia, South America," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 1, pp. 156–59.
ZWICK, BEN F. (1941), "Dehydration and Desalting of Colombian Crude," *Oil Weekly*, Vol. 101, No. 10 (May 12, 1941).

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 8 (AUGUST, 1945), PP. 1143-1155, 2 FIGS.

BRAZER (MISSISSIPPIAN) AND LOWER WELLS (PENNSYLVANIAN) SECTION AT DRY LAKE, LOGAN QUADRANGLE, UTAH[1]

J. STEWART WILLIAMS[2] AND JAMES S. YOLTON[2]
Logan, Utah

ABSTRACT

Further data are given on the Dry Lake section of Mississippian and Pennsylvanian rocks in northern Utah. In a previous paper by the senior writer the Brazer formation (Mississippian) and Wells formation (Pennsylvanian) were recognized, and the Brazer was subdivided into numbered members. Study of additional fossil collections clarifies the correlation of the Brazer with other Mississippian formations of North America. Units 1 and 2 are now proved to be of Iowan age and the Iowan-Chesterian boundary is placed in unit 3. A notable aid to broader correlations is the discovery near the top of unit 2 of the *Goniatites-Girtyoceras* fauna previously cited by Miller and Furnish from many localities and formations elsewhere in the United States.

In the basal Wells formation at Dry Lake are early Pennsylvanian ("Bendian") rocks. These yield a faunule with strong affinities to that of the Morrow formation of Arkansas and Oklahoma. Above the "Bendian" rocks are Desmoinesian rocks with *Wedekindellina* n. sp. This *Wedekindellina* zone marks a horizon that is widely recognized in the Pennsylvanian formations of the west.

INTRODUCTION

Wellsville Mountain lies along the west side of southern Cache Valley (Fig. 1). Southern Cache Valley extends well into the Logan Quadrangle, but all of the mountain, except only a small part of its southeastern end, lies west of the quadrangle boundary. In a recent paper the senior writer described the Carboniferous formations in and adjacent to the Logan Quadrangle (Williams, 1943, p. 594–96). Sections of the Brazer formation in Blacksmith Fork and at Dry Lake, and of the Wells formation near Deweyville, in Secs. 10 and 11, T. 11 N., R. 2 W., were presented. At that time the Wells rocks at Dry Lake were not measured because there the formaton is incomplete at the top.

Subsequently, the writers have collected extensively from the Brazer formation at Dry Lake and have measured more than 1100 feet of Wells beds in that section. We retain the numbers given to the five units of the Brazer formation in the earlier paper, and have designated the lower 440 feet of the Wells formation unit 6, the remainder unit 7. Our measurement ends (top of unit 7) at the zone of *Wedekindellina* n. sp. This zone lies within the basal 170 feet of the Wells section near Deweyville (Williams, 1943, p. 594).

REVIEW OF LITHOLOGY

Lithologic descriptions of the five members recognized in the Brazer section at Dry Lake were published in the earlier paper, and they are repeated here merely for the convenience of readers. Above them is a similar description of the

[1] Manuscript received, March 7, 1945.

[2] Utah State Agricultural College, department of geology.

Part of the fossils were collected by Phyllis Wilcken who began the study of the Brazer limestones at Dry Lake, but was unable to complete the work. The writers are grateful to Carl O. Dunbar for reading the paper and offering valuable suggestions, and for identifying the fusulinids. They are likewise indebted to A. K. Miller for checking identification of the Meramec cephalopod fauna, and to Chalmer L. Cooper for identifying the micro-fossils from the Morrow horizon.

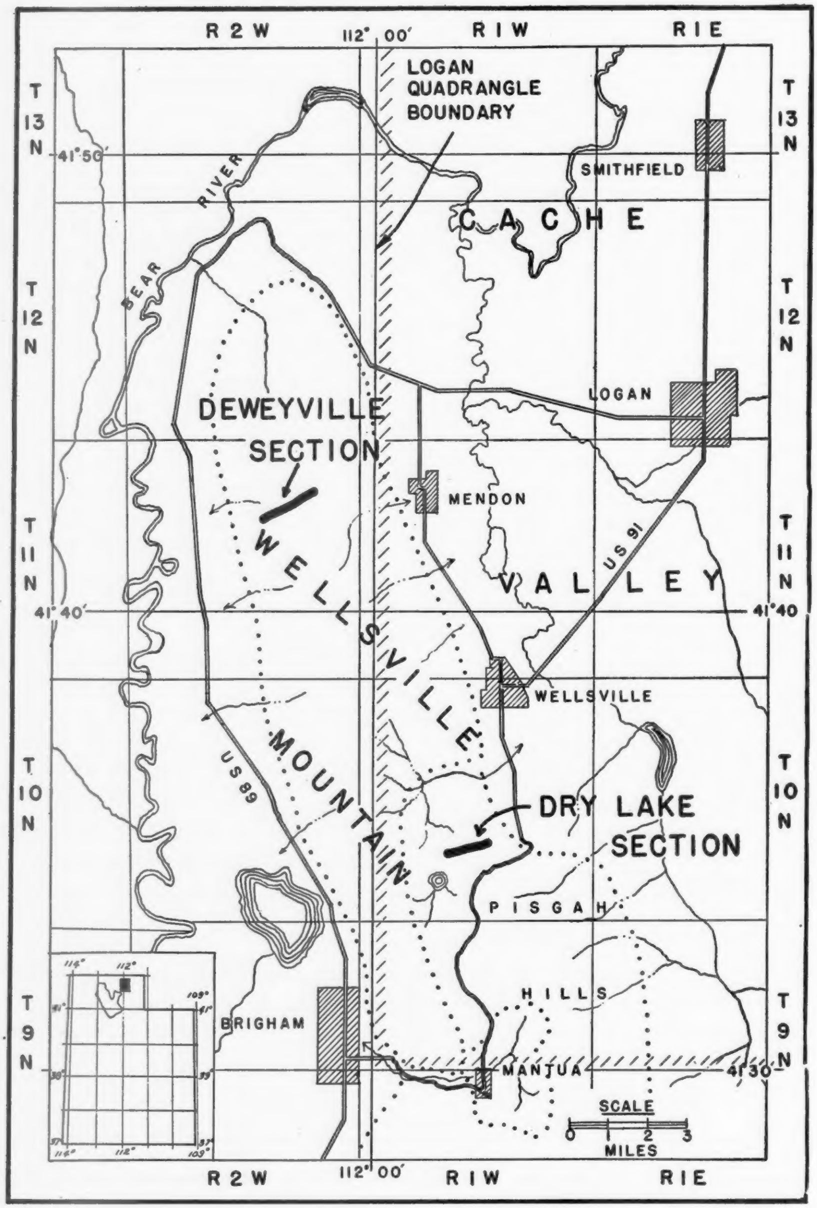


FIG. 1.—Map showing location of Wellsville Mountain and the Dry Lake and Deweyville sections.

1140 feet of the Wells formation up to the *Wedekindellina* zone. Further study affirms the position of the Brazer-Wells boundary, originally drawn, wholly on lithologic grounds, at the base of the first thick sandstone member, since this sandstone has yielded Pennsylvanian fossils. A measured thickness for unit 1, replacing the estimated one previously published, was obtained from the west slope of Mt. Pisgah in Sec. 3, T. 9 N., R. 1 W. This value of 900 feet may be in error by several hundreds of feet due to the numerous faults of small displacement that cut the west face of the hill, but it is the best obtainable in the area. It increases the total for the Brazer at this locality to 3,700 feet. By pace and compass traverse, this member is 650 feet thick at Deweyville. It is 830 feet in Blacksmith Fork Canyon.

The other units of the Brazer formation had been measured across the hill (Williams, 1943, Pl. 1, Fig. 2, foreground) at the north boundary of Sec. 28, T. 10. N., R. 1 W. To obtain the thickness of the basal Wells formation, the traverse was carried eastward into Sec. 27.

DRY LAKE SECTION

WELLS FORMATION (part)	*Feet*
7. Mostly medium- to thick-bedded gray sandstone and calcareous sandstone, with considerable limestone, and with considerable thin-bedded fine-grained sandstone or siltstone weathering buff or quaker-drab. A few thin beds of black shale. Some beds of limestone and sandy limestone have much chert. Measurement terminated upward at top of *Wedekindellina* zone	700
6. Medium-bedded calcareous sandstone weathering brown	440
Total	1,140
BRAZER FORMATION	
5. Mostly thin-bedded fuscous-black to gray silty limestone and calcareous siltstone weathering generally pale purple drab. Some fuscous-black platy shale weathering olive-buff. Also some dark gray thick-bedded compact to crystalline limestone. About 100 feet above base of unit is a thin member with abundant silicified fossils, most comonly *Chonetes loganensis*. These beds lie across summit between Dry Lake and head of Sardine Canyon	950
4. Medium- to thick-bedded crystalline to compact dark gray limestones with considerable smoke-gray and black chert. Lower 200 feet thinner bedded, with much smoke-gray chert showing Liesegang banding. *Caninia* common throughout. Top of unit forms crest of hill.	950
3. Thin- to medium-bedded grayish olive argillaceous limestone weathering olive-buff, alternating with thin units of medium- to thick-bedded compact to crystalline limestone. In some parts, silty limestone grades into fuscous-black shale weathering olive-buff. High in unit is a bed of limestone packed with shells of *Striatifera* (?) *brazeriana*	470
2. Thick-bedded medium- to dark-gray crystalline to compact limestone. *Lithostrotion whitneyi* common	400
1. Drab slightly calcareous sandstone that weathers to wood-brown or cinnamon-drab. Upward this unit grades through alternations of sandstone and limestone into gray limestones. "Worm" fossils common in sandstone	900
Total	3,700

FAUNAL ZONES IN BRAZER FORMATION

The distribution of the various species of the Brazer fauna is shown in Table I. Comments on the composition and age-value of the faunule of each unit follow.

Unit 1.—Prominent in the faunule of this unit is a large *Cliotyyridina* identified as *C. obmaxima* (McChesney), a *Spirifer* very near *S. arkansanus* Girty, a large productid that may be *Marginirugus magnus* (Meek and Worthen), and a species of *Syringothyris*. Only fragmentary external molds of the brachial valve

TABLE I

Distribution of Brazer Fossils

Species	Unit 1	2	3	4	5
Endothyra sp.		x			
Sponge sp. A					x
Sponge sp. B		x			
Sponge sp. C					x
Caninia sp.				x	x
Zaphrentis excentrica Meek				x	
Z. stansburyi Hall		x		x	?
Lithostrotion whitneyi Meek		x			
L. sp. A	x	x			
L. sp. B		x			
Lithostrotionella sp. A		x			
L. sp. B		x			
Lophophyllidium sp.	x	x			
Chaetetes sp.				x	
Syringopora, 3 species		x			
Abolostoma baileyi Peck		?	?	?	
Pentremites subconoideus Meek			x		
P. cf. *P. gondoni* Defrance		x			
P. conoideus Hall		?	?	?	
Mesoblastus sp.			x		
Echinoid spines			x		
Lingula cf. *L. gorbyi* Miller					x
L. sp.			x		
Orbiculoidea cf. *O. keokuk* (Gurley)					x
O. sp.					x
Rhipidomella sp. A					x
R. sp. B	x				
Schizophoria sp.	x				
Schuchertella cf. *S. lens* White					x
S. sp.					x
Orthotetes kaskaskiensis McChesney					x
Streptorhynchus minutum Cummings					x
Chonetes loganensis Hall and Whitfield					x
C. cf. *C. geniculatus* White					x
C. sp. A			x		
C. sp. B					x
Productella cf. *P. pyxidata* Hall					x
P. cf. *P. concentrica* Hall	x				
Striatifera (?) *brazeriana* (Girty)		x	x		
S. (?) *brazeriana* (Girty), small var. ?		x			
Pustula sp.			x		
Echinoconchus alternatus (Norwood and Pratten)		x	x		
Linoproductus altonensis (Norwood and Pratten)		x			
L. ovatus (Hall)		x			x
L. tenuicostus (Hall)			x		x
Productus elegans Norwood and Pratten		?	?		x
Dictyoclostus inflatus (McChesney)			x		x
D. scitulus (Meek and Worthen)		x			x
D. cf. *D. mesialis* (Hall)					x
D. sp.	x				
Marginirugus magnus (Meek and Worthen) ?	x				
Buxtonia sp.					x
Leiorhynchus carboniferum Girty					x
Pugnoides ottumwa (White)			x		
P. parvulus Girty				?	
Centronella sp.			x		
Dielasma cf. *D. arkansanum* Weller					x
**Girtyella turgida* (Hall)					
**G. brevilobata* (Swallow)					
G. sp.			x		x

TABLE 1—*Continued*

Species	Unit 1	2	3	4	5
Cranaena cf. C. *occidentalis Girty*		x			
Spirifer brazerianus Girty				x	x
S. pellaensis Weller					x
S. pellaensis var. *cavecreekensis* Hernon		x			
S. pellaensis var.			x		
S. leidyi Norwood and Pratten				x	
S. cf. *S. breckenridgensis* Weller	x				
S. cf. *S. arkansanus* Girty	x				
Syringothyrus sp.	x				
Spiriferella sp.	x				
Recticularia setigera (Hall)					x
Ambocoelia sp.		x	x		
**Martinia* sp. A					
M. sp. B		x			
Punctospirifer spinosa (Norwood and Pratten)	x		x		x
Eumetria cf. *E. verneuliana* (Hall)			x		
E. sp.					x
Cliothyridina hirsuta (Hall)		x	x		
C. obmaxima (McChesney)	x				
C. sublamellosa (Hall)					x
Composita sulcata Weller			x		x
C. trinuclea Hall				x	x
C. subquadrata Hall					x
C. sp.					x
Solemya sp.					x
Leda cf. *L. bellistriata* Stevens					x
Yoldia sp. A			x		
Y. sp. B					x
Parallelodon sp.			x		
Streblopteria simpliciformis imarginata Girty			x		
Leptodesma occidentale Girty					x
Aviculopinna cf. *A. nebraskensis* Beede					x
Myalina sp. A			x		
M. sp. B			x		
Shizodus curtiforme Walcott			x		
S., several species			x		x
Aviculopecten, several species		x	x		x
Deltopecten cf. *D. texanus* Girty			x		
Caneyella nasuta Girty ?			x		
Limatula (?) sp.					x
Allorisma sp. A			x		
A. sp. B			x		
Cypricardinia sp.			x		
Cypricardella gibbosa Girty		?			
Pleurophorus (?) sp.					x
Bellerophon sp.					x
Pleurotomaria pealeana Girty			x		
Straparollus spergenensis Hall		x			
S. spergenensis var. *planispira* Hall		x			
S., several species		x			
S. (*Euomphalus*), several species		x			x
Naticopsis sp.		x			
Meekospira sp.		x			
Streptacis sp. A		x	x		
S. sp. B		x			
Capulus striatus Girty		x			
C. sp.		x			
Scalites sp. (?)		x			
Bulimorpha elegans Girty					x
Mooreoceras (?), several species					x
Bactrites (?), several species		x			

TABLE 1—*Continued*

Species	Unit 1	2	3	4	5
Dolorthoceras (?) sp.			x		
Tripteroceroides sp.		x			
Discitoceras cf. *D. sulcatum* (Sowerby)		x			
Solenochilus sp.		x			
Planetoceras sp.		x			
Cravenoceras cf. *C. nevadense* Miller and Furnish		x			
Girtyoceras cf. *G. meslerianum* Girty		x			
Goniatites sp.		x			
Paladin cf. *P. moorei* (Branson)					x

of the productid have yet been collected, and the ribbing on them appears somewhat too coarse for that of *Marginirugus*, but better material may prove the presence in this unit of a species widespread at the Warsaw horizon in Kentucky (Weller, 1931, p. 256). There is nothing intrinsic in this assemblage that permits precise correlation, but when it is considered with regard to its position above the Madison and beneath a unit with a distinctly Meramec fauna, it seems very probable that Unit 1 is the equivalent of the Warsaw formation.

Unit 2.—The most conspicuous fossils among the ledges of this unit are *Lithostrotion* and *Syringopora*. Many of the former are *L. whitneyi*, but there are two other forms, a rather rare one with narrow corallites, and a common one with wide non-columellate corallites. The former also occurs in unit 1, the other appears limited to unit 2. *Lithostrotionella* is abundant near the base of this unit on Mt. Pisgah. *Zaphrentis stansburyi* is found abundantly in unit 2, and a small species of *Lophophyllidium* ranges at least from the top of unit 1 into unit 2. This abundance of *Lithostrotion*, of course, suggests the St. Louis limestone, although the species are distinct from those in the Mississippi Valley.

Among the brachiopods, *Linoproductus altonensis* and *Dictyoclostus scitulus* are particularly notable, the first being a Salem form, the second characteristic of the St. Louis. *Cliothyridina hirsuta* has a range co-extensive with the Meramec group (Weller, 1913, p. 481), here ranging through units 2 and 3. *Striatifera* (?) *brazeriana* is present in unit 2 but is much more common in unit 3.

The cephalopod fauna found near the top of unit 2 seems particularly important for correlation. Of the ten genera listed by Miller and Furnish (1940, p. 357) as comprising the Meramec cephalopod fauna from Rockcastle County, Kentucky, the writers have collected the following.

Goniatites sp.
Girtyoceras cf. *G. meslerianum* Girty
Bactrites, several species
Tripteroceroides sp.
Discitoceras cf. *D. sulcatum* (Sowerby)
Solenochilus sp.

With these is another form here identified as *Cravenoceras* cf. *C. nevadense* Miller and Furnish. According to these workers, *Goniatites* and *Girtyoceras* are especially significant, both being represented in Western Europe only in the Visean, the former characteristic of the upper Visean horizon, the latter ranging through the middle and upper Visean. In North America these genera characterize a horizon that has been recognized in the Caney shale of Oklahoma, the Moorefield shale

(and the Batesfield sandstone ?) of Arkansas, the Barnett shale of central Texas the Helms formation of West Texas, and the Floyd shale of Georgia (Miller and Furnish, 1940, p. 357). *Triptero ceroides* is a new genus from this horizon in Kentucky, where *Discitoceras* and *Solenochilus* also were reported. *Discitoceras*, according to a personal communication from Miller, is a reliable guide to the Meramec horizon. The discovery of the *Goniatites-Girtyoceras* fauna in unit 2 greatly strengthens its correlation as Meramec, and proves its general equivalence to the formations here listed.

Unit 3.—In the argillaceous, olive-buff-weathering limestones of this unit, pelecypods and the brachiopod *Striatifera* (?) *brazeriana* are most apparent. To date the writers have been unable to identify specifically a majority of the pelecypods, as the faunal list shows, and some of them may be new, but *Caneyella nasuta* (*?*) is suggestive, although the specimens are too poor to make a positive identification possible. *Streblopteria simpliciformis* var. *imarginata* and the snail *Pleurotomaria pealeana* are listed (1927, p. 69, 70) with Girty's, "Spergen facies" of the Brazer fauna. *Pugnoides ottumwa* (White) is an important guide fossil to the Ste. Genevieve. *Cliothyridina hirsuta* is a Meramec form. Although rare in unit 2, *Striatifera* (*?*) *brazeriana* is packed in great abundance in some beds of unit 3. Thus, there are several elements in the fauna of this unit which indicate a Meramec age, but the presence of those now to be listed, that belong to the younger assemblages of units 4 and 5, lead the writers to the present time to consider the fauna of unit 3 transitional between Meramec and Chester.

The Chesterian elements in the fauna of unit 3 are *Composita sulcata*, *Dictyoclostus inflatus* and questionably, *Productus elegans*. This is scanty evidence even in a faunal list that is not extensive, and particularly in view of the preponderance of Meramec forms, but it must be considered. Hence, the Iowan-Chesterian boundary is at present drawn in this unit.

Unit 4.—Most easily collected from the beds of this unit are specimens of a large form of *Caninia*, but other common corals are *Chaetates* sp., and *Zaphrentis stansburi*. Misinformation about the correlation of the limestone ledges at the top of Mt. Pisgah with the published section, led to the erroneous listing of both species of *Lithostrotionella* from this unit (Williams, 1943, p. 596). Neither has been found here. Topotypes of *Zaphrentis excentrica* Meek have been collected from these beds.

In Girty's experience (1927, p. 71) *Spirifer brazerianus* is definitely associated with *Camarophoria explanata* and is indicative of the Chester. The writers have not yet collected the latter, but *S. brazerianus* has not been found in their section below this unit. *Spirifer leidyi* is a Chester form, and *Composita trinuclea* is most characteristic of lower and middle Chester. All considered, there seems little doubt that unit 4 definitely is Chesterian, in age, and probably represents the older part of the Late Mississippian.

Unit 5.—As with the other units, the number of species identified from this uppermost member of the section is not great, but they likewise seem clearly to

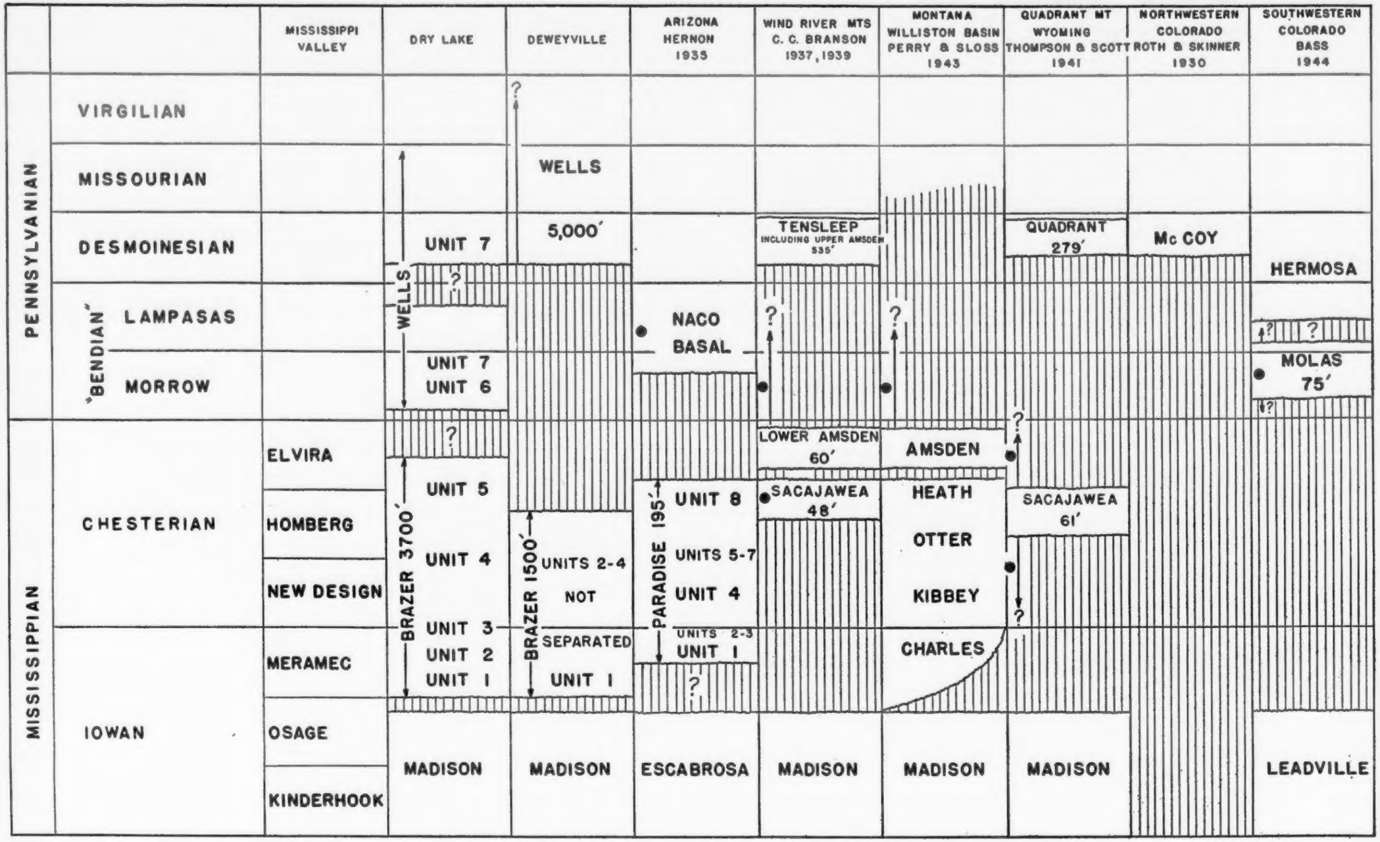


FIG. 2.—Correlation of Dry Lake and Deweyville sections with other sections in Rocky Mountain region. Solid circles on chart appear where stratigraphic position, or suggested position, of units is the writers' own interpretation.

indicate a Chesterian age. Among such are *Spirifer pellaensis*, *S. brazerianus*, *Orthotetes kaskaskiensis*, *Cliothyridina sublamellosa*, *Composita subquadrata*, and *Productus elegans*. Though much of the silty limestone fossils are rather rare, and a more exact correlation with the subdivisions of the type Chester is not possible, except that considering the combined thickness of units 4 and 5, 1900 feet, it seems that here the record of the Chesterian epoch should be complete, or nearly so. A search for ostracods in unit 5 to improve the correlation has not as yet been successful.

CORRELATIONS OF BRAZER WITH OTHER FORMATIONS IN WEST

The relationship of the Dry Lake section of the Brazer formation to the Paradise, Sacajawea, and Amsden formations, and to the Big Snowy group is shown in Figure 2. Since the unnamed limestone below the Paradise formation is correlated with the St. Louis limestone (Hernon, 1935, p. 660), unit 1 at Dry Lake is probably older than any part of the Paradise formation. Hernon's units 1, 2, and 3 appear to be the approximate time equivalents of the writers' units 2 and 3. Since it seems impossible at present to correlate the upper part of our Mississippian section with the subdivisions of the Chester, it is difficult to compare units 4 and 5 at Dry Lake with units 4 to 8 of the Paradise formation. However, with the former comprising 1900 feet of rocks, compared with 80 feet in the latter, it seems very probable that there is a considerable thickness of rocks at Dry Lake younger than any part of the Paradise formation. Perhaps a large part of unit 5 is younger.

The Sacajawea formation has been called Ste. Genevieve in age (Branson, 1937; Morey, 1935), and that age-determination has been questioned (Croneis and Funkhouser, 1938). Some little evidence at hand from the Dry Lake section appears to lend support to the view that it is somewhat younger than Ste. Genevieve. Although *Orthotetes kaskaskiensis* appears in the Ste. Genevieve limestone of the Mississippi Valley (Weller, 1914, p. 78) and ranges into the Chester group, it is limited to the Chester units of the Paradise formation (Hernon, 1935, p. 669) and so far as known to unit 5 at Dry Lake. The smaller individuals of *Chonetes loganensis* Hall and Whitfield are near *C. chesterensis* Weller, and they are abundant near the base of unit 5 in association with a species of *Paladin* which is very near to *Paladin moorei* (Branson).

Figure 2 is intended to indicate only the general relationship between the Brazer formation and the Big Snowy group, since the megafauna of the latter has not yet been described, and the microfauna of the former is not known. It suggests that the fauna of the Amsden formation of the Williston Basin area (Perry and Sloss, 1943, p. 1293) may be the age of unit 6 or lower unit 7 at Dry Lake, that is, earliest Pennsylvanian.

Closer correlation of the Brazer section at Dry Lake with the thick sections of upper Mississippian rocks 180 miles northwest in the Mackay Region, Idaho (Umpleby, 1917, p. 27), 100 miles south southwest in the Oquirrh Mountains,

Utah (Gilluly, 1932, p. 25–34), and 230 miles southwest in White Pine County, Nevada, await detailed stratigraphic studies of these sections.

FAUNULES IN BASAL PART OF WELLS FORMATION

The change in lithology from unit 5 to unit 6 is marked, and represents generally the contrast between the Brazer and Wells formations, the former consisting essentially of limestones (unit 1 excepted), the latter of calcareous sandstones, although the lower part of unit 7 repeats some of the lithologic types found in unit 5. That this lithologic change marks the Mississippian-Pennsylvanian boundary is supported by the fact that unit 6 yields Pennsylvanian fossils; and unit 6 probably lies unconformably on the Brazer, as indicated in Figure 1, although this relationship has not yet been observed directly. Fossils collected from unit 6 are the following.

Linoproductus prattenianus (Norwood and Pratten)
Juresania nebraskensis (Owen)
Dictyoclostus inflatus var. *coloradoensis* (Girty)

This collection was made along the dugway where Highway 91 skirts the head of Sardine Canyon, trending northward for a short distance near the west boundary of Sec. 27, T. 10 N., R. 1 W.

A bed of shale near the base of unit 7 contains a faunule of particular interest. This bed crops out along the highway at the very beginning of the road cut or dugway where the short northerly trend of the road swings at right angles into the long easterly trend down to the mouth of the canyon. The shale is comparatively soft, and weathers quaker drab. The megascopic forms in the faunule are the following.

Schizophoria texana Girty
Chonetes cf. *C. granulifer* var. *armatus* Girty
Dictyoclostus inflatus far. *coloradoensis* Girty
D. portlockianus (Norwood and Pratten)
D. portlockianus var.
Pugnoides sp.
Dielasma, several sp.
Spirifer rockymontanus Marcou
S. matheri Dunbar and Condra
S. occidentalis Girty
Ambocoelia sp.
Eumetria sp.
Nucleospira sp.
Cliothyridina orbicularis McChesney
Composita cf. *C. ozarkana* Mather
Paladin sp., near *P. morrowensis* Mather

The microscopic forms, which were identified by Chalmer L. Cooper, are here listed with his notes on their stratigraphic range.

Bryozoa	
Rhombopora vitidula, Harlton	Wapanucka and Johns Valley formations of Oklahoma
R. johnsvalleyensis Harlton	Wapanucka and Johns Valley formations of Oklahoma
Cystodictya elegens Harlton	Wapanucka and Johns Valley formations of Oklahoma
Fenestella granularis Harlton	Wapanucka and Johns Valley formations of Oklahoma
Ostracoda	
Glyptopleura n. sp.	Similar to *G. coryelli* but ribs are thinner and posterior end wider. Similar form in Marble Falls of Texas
Microparaparchites wapanuckensis (Harlton)	Common in Wapanucka and Otterville of Oklahoma and Marble Falls of Texas. Occurs in higher zones in Illinois
Paraparchites cf. *P. claytonensis* Knight	Known from pre-Des Moines beds in Illinois and Pawnee limestone of Missouri
Healdia caneyensis Harlton	Wapanucka, Marble Falls and ? upper Chester
Healdia marginata Harlton	Springer, Wapanucka and ? Caney of Oklahoma

Healdia cf. *H. farmosa* Harlton	Dimple (Morrow), Texas
Bairdia ardmorenesis Harlton	Limestone Gap shale (Morrow), Oklahoma
Cavillina robusta Bradfield	Joliff limestone and Johns Valley shale, Oklahoma
Jonesina sp. (probably n. sp.)	
Endothyra cf. *E. ovata* Waters	Des Moines and Missouri of Oklahoma and Texas

This assemblage is clearly an early Pennsylvanian fauna, and sufficiently diagnostic to assign the rocks containing it to the Morrow series, without reservation.

The beds of unit 7 are, no doubt, more or less fossiliferous throughout, but in several cursory trips over this part of the section nothing has been collected. At the top of the unit, however, where the measured section ends, fossils are abundant. Outstanding to the collector are well preserved specimens of a species of *Archimedes* and other cryptostomatous bryozoans; but more important for the purpose of correlation is a new species of *Wedekindellina*. This fossil horizon is within 170 feet of the base of the Wells at the north end of Wellsville Mountain (Williams, 1943, p. 594). The faunule at this horizon consists of the following.

Wedekindellina n. sp.	*Derbya crassa* Meek and Hayden
Caninia sp.	*Echinoconchus semipunctatus* (Shepard)
Syringopora, several species	*Dictyoclostus inflatus* var. *coloradoensis* (Girty)
Batostomella, several species	*D. americanus* var. *hermosanus* (Girty)
Chainodictyon sp.	*Marginifera* (?) sp.
Lyropora sp.	*Neospirifer cameratus* (Martin)
Polypora, several species	*N. dunbari* King
Pinnatopora, several species	*Punctospirifer campestris* (White)
Ptilopora sp.	*Composita subtilita* (Hall)

The presence of *Wedekindellina* considered with the other elements of the faunule, indicates clearly a Demoinesian age. This horizon, then, runs also through the Tensleep of Wyoming (Branson, 1939), the Quadrant of Wyoming and Montana (Thompson and Scott, 1941), the McCoy (Roth and Skinner, 1930) and Hermosa (Roth, 1934) of Colorado, and the Des Moines series, probably the Garcia formation, of New Mexico (Thompson, 1942). It is essentially the horizon of the basal Weber on the Duchesne River and the Morgan on Brush Creek, Uinta Mountains, Utah (Williams, 1943, p. 604, 607).

TRITICITES ZONE IN WELLS FORMATION

The senior writer has reported in the earlier paper (Williams, 1943, p. 594) that *Triticites* is abundant from 1000 to 2000 feet above the base of the Wells section near Deweyville, that is, above the horizon where *Wedekindellina* n. sp. is abundant. A complete collection from all horizons in this interval is not yet available, but it is of interest that of the three lots of fusulinids that have been examined from this interval, all have been reported to be of late Missourian age. This indicates the possibility of locating an important unconformity in the Wellsville Mountain section of the Wells formation between the Desmoinesian and Missourian rocks.

Following is a summary of the report of Dunbar on the age of fusulinids from the *Triticites* zone.

(1) Sec. 10, T. 11 N., R. 2 W., ridge on west face of Wellesville Mountain, southeast of Deweyville. *Triticites* n. sp. "of about the stage of evolution seen in *T. cullomensis*. This is a conservative type of *Triticites* and it is difficult to distinguish between several species and impossible to limit the horizon closely. However, the age is certainly high in the Missourian series or more likely low in the Virgilian."

(2) Sec. 33, T. 12 N., R. 2 W., talus at the south side of the mouth of North Maple Canyon. *Triticites* n. sp., same as above.

(3) Sec. 32, T. 11 N., R. 1 W., north side of the mouth of Pine Canyon. *Triticites* near *T. gallowayi* Needham. Age, late Missourian.

A subdivision of the thick section of the Wells formation in Wellsville mountain, now known to total approximately 6,000 feet, into the series of the standard section can now be attempted in a very preliminary way. Across Cache Valley at the east, in Blacksmith Fork Canyon, and still farther east in Brazer Canyon, the Brazer and Wells formations are separated by an unconformity of great magnitude. The same is true a short distance north-northwest at the north end of the mountain near Deweyville. Mansfield (1927, p. 73) recognized the unconformable relationship of the two formations in southeastern Idaho. This unconformity may extend into the Dry Lake section either as a single break above or below the earliest Pennsylvanian rocks, or, as seems more probable, as breaks both above and below the "Bendian" series. The lithologic change between units 5 and 6 is sufficiently marked to suggest unconformity at the base of the Pennsylvanian; another break, as yet undiscovered, is probably present in unit 7, but until it is known, the base of the Des Moines series can not be indicated. There are at least 450 feet of earliest Pennsylvanian, "Bendian" rocks and probably several hundred feet more.

If the Missourian series be considered as marked by the present known range of *Triticites*, then it extends from approximately 1000 to 2000 feet above the *Wedekindelline* zone, the base of the Wells section at the north end of Wellsville Mountain (Williams, 1943, p. 594), and the top of the measured section at Dry Lake. This would leave a maximum of approximately 1,700 feet, and a minimum of 1,000 feet that may be Desmoinsian in age. If the Missourian series ends with the present known range of *Triticites*, then there are still 3,000 feet of rocks not younger, as far as is known, than Pennsylvanian, to be assigned to the Virgilian series.

SUMMARY OF CONCLUSIONS

1. The thick (3,700 feet) section of the Brazer formation at Dry Lake includes rocks of Iowan and Chesterian age, extending probably from an equivalent of the Warsaw to latest Chester.

2. The reported vertical distribution of fossils should be helpful in correlating other sections of Mississippian rocks in the Rocky Mountain region. A Meramec cephalopod horizon discovered in the lower Brazer should be particularly useful for this purpose.

3. The various members of the Dry Lake section can be correlated satisfactorily with the members of the Paradise formation in Arizona, and tentatively with the Sacajawea formation of central Wyoming.

4. The Brazer is overlain by several hundreds of feet of rocks that are earliest Pennsylvanian ("Bendian") in age. Their thickness is not yet definitely determined, but lies between limits of 450 and 1,000 feet. At one horizon they contain a fauna with marked affinities to that of the Morrow formation of Arkansas and Oklahoma. This horizon clearly belongs in the Morrow series. Whether rocks of the Lampasas series are present is not known.

5. At 1140 feet above the top of the Brazer formation is the widely distributed Desmoinesian fauna with *Wedekindellina* n. sp., which is found also in the Tensleep, Quadrant, McCoy, and Hermosa formations of near by states.

6. The Wells formation rests on the Brazer formation in this region with profound unconformity which reduces the thickness of the latter to half, 11 miles north northwest near Deweyville, and 12 miles east northeast in Blacksmith Fork Canyon.

7. The absence of "Bendian" rocks in the section at Deweyville suggest the presence of another unconformity in the Dry Lake section between the "Bendian" and Desmoinesian rocks.

REFERENCES CITED

BASS, N. W. (1944), "Paleozoic Stratigraphy as Revealed by Deep Wells in Parts of Southwestern Colorado, Northwestern New Mexico, Northeastern Arizona, and Southeastern Utah," *U. S. Geol. Survey Prelim. Chart 7*, Oil and Gas Inves. Ser. (1944). Text to accompany chart.

BRANSON, C. C. (1937), "Stratigraphy and Fauna of the Sacajawea Formation, Mississippian, of Wyoming," *Jour. Paleon.*, Vol. 11, pp. 650–60.

——— (1939), "Pennsylvanian Formations of Central Wyoming," *Bull. Geol. Soc. America*, Vol. 50, pp. 1199–1226.

CRONEIS, C., and FUNKHOUSER, H. J. (1939), "New Ostracods from the Clore Formation," *Denison Univ. Bull., Jour. Sci. Labs.*, Vol. 33, pp. 331–60.

GILLULY, J. (1932), "Geology and Ore Deposits of the Stockton and Fairfield Quadrangles, Utah," *U. S. Geol. Survey Prof. Paper 173*.

GIRTY, G. H. (1927), quoted in MANSFIELD, G. R., "Geography, Geology, and Mineral Resources of a Part of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper 152*.

HERNON, R. M. (1935), "The Paradise Formation and Its Fauna," *Jour. Paleon.*, Vol. 9, pp. 653–96.

MATHER, K. F. (1915), "The Fauna of the Morrow Group of Arkansas and Oklahoma," *Denison Univ. Bull., Jour. Sci. Labs.*, Vol. 18, pp. 59–251.

MANSFIELD, G. R. (1927), "Geography, Geology, and Mineral Resources of a Part of Southeastern Idaho," *U. S. Geol. Survey Prof. Paper 152*.

MILLER, A. K., and FURNISH, W. M. (1940), "Studies of Carboniferous Ammonoids: Parts 1–4," *Jour. Paleon.*, Vol. 14, pp. 356–77.

MOREY, P. S. (1935), "Ostracoda from the Amsden Formation of Wyoming," *Jour. Paleon.*, Vol. 9, pp. 474–82.

NOLAN, T. B. (1943), "The Basin and Range Province in Utah, Nevada and California," *U. S. Geol. Survey Prof. Paper 197-D*.

PERRY, E. S., and SLOSS, L. L. (1943), "Big Snowy Group: Lithology and Correlation in Northern Great Plains," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, pp. 1287–1304.

ROTH, R. (1934), "Type Section of Hermosa Formation, Colorado," *Bull. Amer. Assoc. Petrol. Geol.* Vol. 18, pp. 944–47.

———, and SKINNER, J. (1930), "The Fauna of the McCoy Formation, Pennsylvanian, of Colorado," *Jour. Paleon.*, Vol. 4, pp. 332–52.

THOMPSON, M. L. (1942), "Pennsylvanian System in New Mexico," *New Mexico School Mines Bull. 17*.

———, and SCOTT, H. W. (1941), "Fusulinids from the Type Section of the Lower Pennsylvanian Quadrant Formation," *Jour. Paleon.*, Vol. 15, pp. 349–53.

UMPLEBY, J. B. (1917), "Geology and Ore Deposits of the Mackay Region, Idaho," *U. S. Geol. Survey Prof. Paper 97*.

WELLER, S. (1914), "The Mississippian Brachiopoda of the Mississippi Valley Basin," *Illinois Geol. Survey Mon. 1*.

WELLER, J. M. (1931), "The Mississippian Fauna of Kentucky," *Kentucky Geol. Survey*, Ser. 6, Vol. 36, pp. 251–90.

WILLIAMS, J. STEWART (1943), "Carboniferous Formations of the Uinta and Northern Wasatch Mountains, Utah," *Bull. Geol. Soc. America*, Vol. 54, pp. 591–624.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 8 (AUGUST, 1945), PP. 1156-1168, 10 FIGS.

LIMESTONE RESERVOIR CONDITIONS IN TURNER VALLEY OIL FIELD, ALBERTA, CANADA[1]

A. J. GOODMAN[2]
Calgary, Alberta

ABSTRACT

Detailed evidence from chemical analyses and from the examination of thin sections of Mississippian limestone samples from wells drilled in the Turner Valley oil field, Alberta, Canada, indicate that the porosity of the oil and gas reservoir was produced by the action of meteoric waters previous to the deposition of Jurassic and younger beds upon the eroded Paleozoic surface. There is also evidence that secondary silicification took place at the same time, and that oil was present in the limestone while this metasomatic action was proceeding.

Many wells drilled for oil in western Canada have failed to produce commercially because porosity in the Paleozoic limestone was unfavorable. In the Turner Valley oil field certain areas were left undrilled because a few test wells indicated low porosity, but recent drilling has shown that these areas are more favorable than was at first anticipated. In the search for new fields a better understanding of reservoir conditions appears to rank in importance with the discovery of suitable structures.

This paper is based on work done previous to 1935, and some conclusions have already been published.[3] Since then others[4,5,6,7] have published information on the same subject, and there are probably many unpublished data of more recent date. It is hoped that revival of this earlier work will stimulate further efforts to attack the many problems awaiting solution.

MARKER HORIZONS

So far comparatively little appears to have been accomplished in the way of establishing reliable marker horizons from well samples of the Mississippian limestone for correlation purposes. There is a fairly persistent band of argillaceous limestone, now referred to as the "Black lime." There is a zone in which the Foraminifera, *Endothyra*, *Ammodiscus*, and *Glomospira*, are fairly prolific, and it is possible to establish some correlation between closely adjacent wells by comparing the sequence of textures and types of limestone. There is still a great need for more detailed stratigraphical information from well samples for closer correlation over longer distances.

[1] Manuscript received, March 25, 1945.

[2] Geologist, Socony-Vacuum Exploration Company.

[3] A. J. Goodman, *Jour. Inst. Petrol. Tech.*, Vol. 21, No. 138 (1935). London.

[4] W. D. C. Mackenzie, "Paleozoic Limestone of Turner Valley, Alberta, Canada," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 24, No. 9 (September, 1940), pp. 1620–40.

[5] H. H. Beach, *Geol. Survey Canada Mem. 236* (1943), pp. 32–33.

[6] W. P. Campbell, *Trans. Canada Inst. Min. Met.*, Vol. 40 (1936).

[7] P. D. Moore, cited by John Emery Adams, "Origin, Migration, and Accumulation of Petroleum in Limestone Reservoirs in the Western United States and Canada," *Problems of Petroleum Geology*, Amer. Assoc. Petrol Geol. (1934), p. 347.

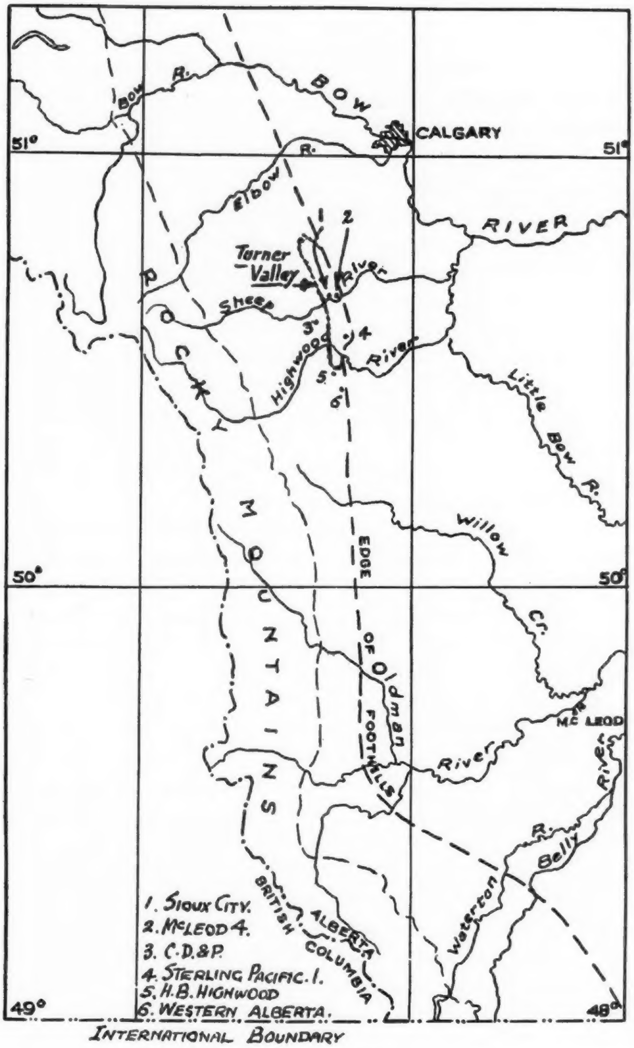


Fig. 1

In the development of the Turner Valley field several zones have been named for drilling purposes, and these have been recorded by Mackenzie,[8] but he

[8] W. D. C. Mackenzie, *op. cit.*

himself has suggested that these are not entirely satisfactory from a geological point of view.

CHEMICAL AND PETROGRAPHIC EVIDENCE

In the present examination thin sections of the limestone have been studied under the microscope and a parallel chemical analysis was carried out by W. P. Campbell.[9] The Sioux City well No. 1 and the McLeod well No. 4 were examined in considerable detail, and other wells in Turner Valley and in other Foothills and Plains areas were also examined more generally.

The chart of chemical analysis by Campbell (Fig. 2) has been correlated with thin-section information in the three wells, Sioux City No. 1, McLeod No. 4, and Sterling Pacific No. 1. Calcite and magnesium carbonate values are shown independently of all other constituents. $CaCO_3$ values are at the left of the shaded area and $MgCO_3$ values are covered by the shaded area. Both are in percentages. Approximation to a pure dolomite is indicated by the nearness of approach of the shaded area to the pure dolomite line. Silica percentages are plotted independently on the same chart.

From the first contact with the Mississippian limestone in the Sioux City well at 4,385 feet down to 4,835 feet, the limestone is for the most part recrystallized, granular, and contains much silica in the form of chert. In places traces of fossils were noted which have escaped complete alteration. These remains are of crinoids, bryozoans, and foraminifera similar to those occurring just beneath the Altered zone. In the McLeod well No. 4 a similar altered zone from 3,730 feet to 4,170 feet was noted, but in the Sterling Pacific well the thickness of the Altered zone is approximately 600 feet, that is, from the top of the limestone down to the first appearance of argillaceous limestone ("Black lime"). The crinoidal bryozoal band found in the other two wells above "Black lime" is missing in the Sterling Pacific well. Apparently alteration has gone deeper in this well.

In the C. D. & P. well west of Turner Valley the top fault block of limestone, approximately 195 feet thick, and 320 feet of the lower block have been altered and recrystallized.

In the Hudson's Bay Highwood well there is also an altered zone, but gaps in the samples do not permit a complete analysis.

The western Alberta well, south of Turner Valley, shows an altered zone, and some Plains wells show varying degrees of silica replacement at the top of the limestone. In general the degree of alteration does not appear to be so marked in the Plains as in the Foothills. This is a point on which further detailed information from recently drilled wells would be of considerable value.

The crinoidal-bryozoal limestone band beneath the Altered zone in the Sioux City well shows very little silica and a moderate magnesium content. From the occurrence of faint traces of crinoidal and bryozoal remains in the Altered zone it is considered probable that before alteration this zone was similar to the un-

[9] W. P. Campbell, *op. cit.*

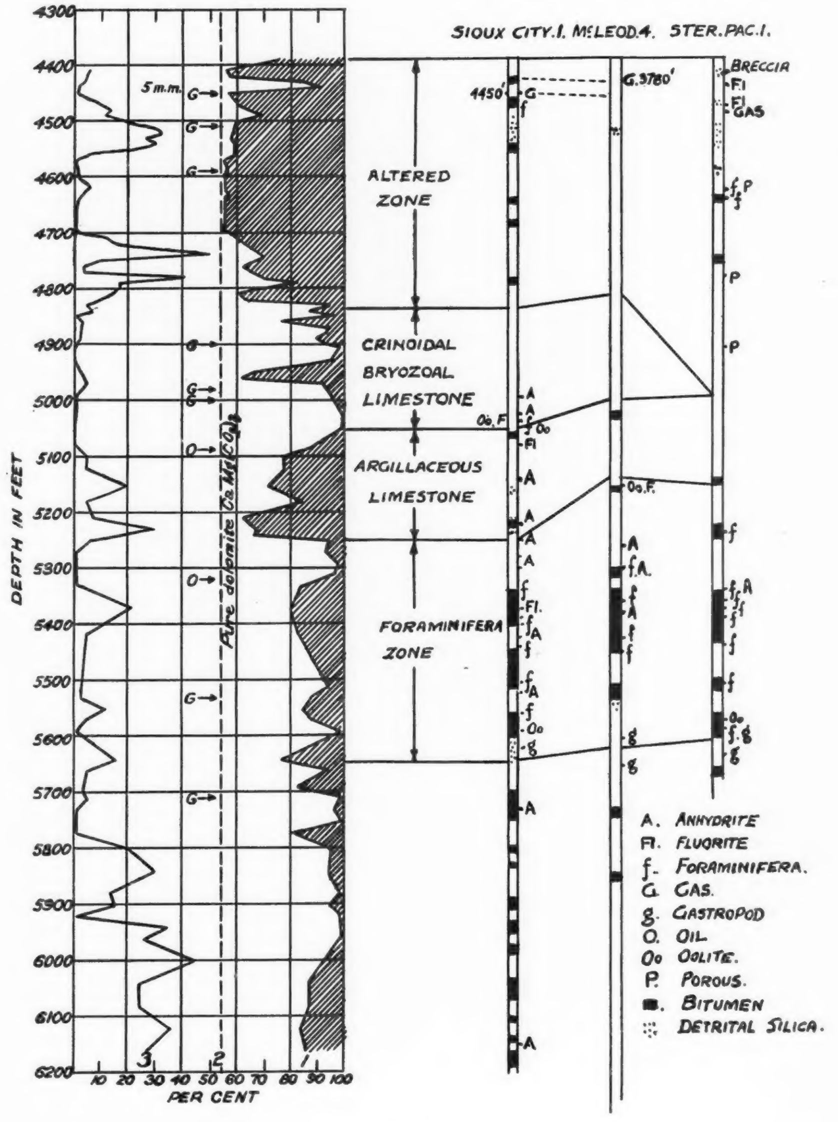

SIOUX CITY.1. MCLEOD.4. STER.PAC.1.
DEPTH IN FEET
PER CENT
Pure dolomite Ca.Mg.(CO3)2
5 m.m.
ALTERED ZONE
CRINOIDAL BRYOZOAL LIMESTONE
ARGILLACEOUS LIMESTONE
FORAMINIFERA ZONE
4450'
G.3780'
BRECCIA
GAS
A. ANHYDRITE
Fl. FLUORITE
f. FORAMINIFERA.
G. GAS.
g. GASTROPOD
O. OIL
Oo OOLITE.
P. POROUS.
BITUMEN
DETRITAL SILICA.

FIG. 2

altered band directly beneath it. This suggests that the high silica values of the Altered zone may indicate epigenetic silica (secondary silicification).

Figure 3 illustrates a thin section of limestone from the McLeod well No. 4 at 3,780 feet. It is from a porous gas-producing zone, but there is much secondary calcite partially filling some pore spaces and completely filling others. The areas marked "X" all extinguish as one calcite crystal under crossed nicols. By comparison of sequences of similar-textured limestone, it is possible to trace this

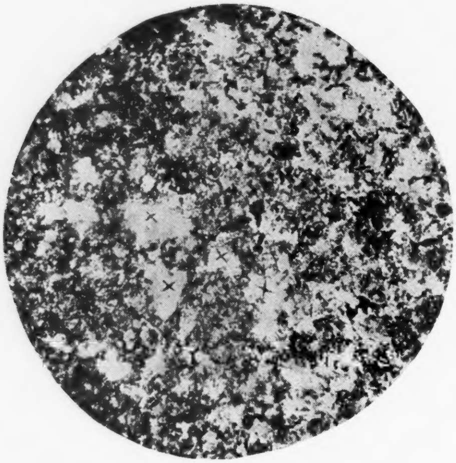


FIG. 3

horizon in the Sioux City well, but in this case the pore spaces are completely filled, and there is no gas. Such infilling coupled with an increase in dolomite content at other points in the Altered zone suggests removal and redeposition of calcite from one part of the rock to another, thereby increasing the dolomite value at some horizons. In addition there has probably been re-solution and recrystallization of dolomite.

Figure 4 shows a spotted porous dolomite from the Sioux City well which produced gas. This horizon can be traced in the McLeod well No. 4, where it is solid and produces no gas. This spotted type of dolomite is characteristic of dolomites found in other regions, It appears to be recrystallized and may be derived from an original oölite. Thus, in the Sioux City well and the McLeod well No. 4 the main wet gas zones are not identical. Each well produces from its own porous zone. The two zones are 10 to 20 feet apart. If we consider this erratic porosity to be an erosional effect and to be general over the whole field, it explains why one well can produce profitably and an adjacent well may be

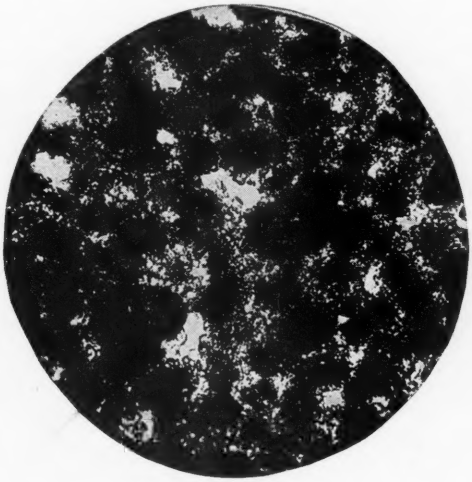


FIG. 4

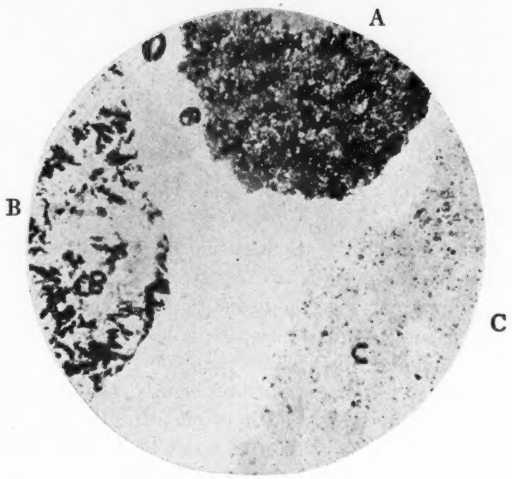


FIG. 5

barren. If we follow the opinion stated by P.D. Moore[10] that "the porosity dies out on the west flank at the point at which the dolomite of the pool area grades into limestone," then it is logical to condemn a whole area as likely to be uneconomical when the results from one or two wells are unsatisfactory. On the

[10] P. D. Moore, *op. cit.*

other hand, if porosity is erratic, then it is not justifiable to rule out any area without adequate testing with the drill.

Silica.—Evidence of secondary silicification is illustrated in Figure 5. The three pieces originally came from the same fragment, but it was broken up to bring them within the microscope field. "A" is a piece of dolomitic limestone containing bitumen adsorbed on the crystal rhombs. This limestone grades into pure silica, but the bitumen retains the rhomb impressions as seen at "B."

FIG. 6

FIG. 7

Fragment "C" was treated with all the usual oil solvents without success, and finally the bitumen was removed by heating strongly in air.

From this it is apparent that metasomatic replacement by silica has taken place, and this corroborates the assumption, based on the chemical evidence, that in the Altered zone most of the silica is epigenetic.

Argillaceous limestone.—As mentioned previously, the crinoidal-bryozoal type of limestone is underlain by a band of limestone containing a high percentage of fine clay material. This is usually referred to as the "Black lime" and included in this term is an underlying band with less clay material and many fossil remains (mainly crinoidal and bryozoal fragments but with many Foraminifera, such as *Endothyra*, *Ammodiscus*, and *Glomospira*, and some minute gastropod forms) (Figs. 6 and 7).

It may be that this Foraminifera zone provides a means of making a more exact correlation with the "Black lime" revealed in other areas, for example, Jumping Pound. In the chemical analysis much of the silica occurring in this zone is derived from silicates (clay) and some from detrital material. The rest is

probably syngenetic. In this close-grained rock there was probably very little primary porosity, and there is no evidence of alteration from circulating water, so that epigenetic silica probably does not occur.

If erosion of the Paleozoic limestone surface had continued to this argillaceous band there might not have been any Turner Valley oil field. Study of such dense argillaceous limestones to see what effect (if any) has been produced upon them by circulating waters is another problem of considerable economic importance, for there may well be structurally favorable areas where the top of the limestone is argillaceous and impervious.

A comparison of the different zones mentioned in this paper with those recorded by Mackenzie shows that all Mackenzie's zones down to the "Black lime" fall within the Altered zone of this paper, but an additional Fossiliferous zone could be added, commencing at about 200 feet from the top of the "Black lime." The bottom of this zone would have to be determined by further study.

Dolomitization and porosity.—Apparently Mackenzie also accepted the opinion that porosity is connected with shrinkage resulting from the formation of dolomite. Most authorities on this subject favor the idea that most dolomitization is a process pene-contemporaneous with deposition, caused by the addition of magnesium from sea water. If any shrinkage should result at this time the voids would for the most part be removed as the rock compacts. Field evidence supports this view, for there are as many dense dolomitic limestones as there are dense pure limestones, and even in the Turner Valley section the proportion of dense hard dolomite is considerably greater than dolomite of the porous variety.

Adams[11] states that "The constant use of dolomitization as an explanation of the increase of porosity in limestone is one of the theories that appear to be overworked."

Beach[12] has also expressed disagreement with this explanation of the cause of porosity in dolomitic limestone.

Adsorbed bitumen.—The next point of interest is the solid bitumen of high carbon content often referred to as pyrobitumen. This appears to be a misnomer as there is no proof that heat has played any part in its formation. P. G. Nutting[13] has done experimental research on this material, and has discovered that the heavier components of oil are selectively adsorbed on to silica, silicates, some carbonates, and other materials in a colloidal state. When adsorbed the bitumen is as firmly attached as if it were in chemical combination, and oil in contact with the adsorbed layer is not easily displaced from small pore spaces. The presence of this adsorbed bitumen is evidence of the former presence of oil. It

[11] J. E. Adams, *op. cit.*, pp. 359–60.

[12] H. H. Beach, *op. cit.*

[13] P. G. Nutting, "Some Physical and Chemical Properties of Reservoir Rocks Bearing on the Accumulation and Discharge of Oil," *Problems of Petroleum Geology*, Amer. Assoc. Petrol. Geol. (1934), pp. 825–32 and references therein.

may also explain why a limestone can be altered, recrystallized, leached, and rendered porous, and still retain the oil. Incidentally, it may in part explain why acidizing increases production. It is commonly thought that acid treatment dissolves carbonates and increases permeability by increasing pore size. This may be only part of the story. It is possible that in dissolving the limestone the acid may break the molecular bonds of the adsorbed bitumen and so set free the oil clinging to it. There may also be some connection here with the behavior of edge water. A pore space coated with adsorbed bitumen becomes hydrophobic (water repellant). An alkaline solution would probably be equally effective in releasing the molecular bonds, but of course would not increase the pore space.

In the limestone sections examined this adsorbed bitumen is very common in the presence of silica or silicates (clay material). Thus it is very common in the "Black lime" and in the Altered zone, but in the pure white crinoidal-bryozoal type of limestone it is rare. It appears probable that at some time oil has been present in this band as it has in most other parts of the limestone. A clean white limestone at outcrop is not therefore necessarily unfavorable evidence of oil-bearing potentialities.

Reference has already been made to Figure 5 in which bitumen shows rhomb-shaped indentations where secondary silicification has replaced dolomite or calcite rhombs. In this case the bitumen could have been adsorbed on to the original crystals which were later completely replaced by silica. Alternatively silica could replace the dolomitic limestone and still retain any small porosity, and the bitumen could be introduced later. As against this, Campbell has noted that in the Sioux City well, wherever there is the slightest porosity at that point silica values are very low.

There is one exception, at 4,510 feet, where the thin sections reveal that the silica content is due, not to secondary silicification, but to detrital quartz in the limestone. On the basis of this and the additional evidence which follows the more probable explanation seems to be that the bitumen was there before silica replacement took place.

Figure 8 illustrates a section of silica with banded agate structure. It is in the Altered zone and therefore probably secondary. Most of the banding is of iron oxide, but near the outer edge is a thick band of adsorbed bitumen and beyond the bitumen there is more silica and then limestone, which also contains bitumen. This type of banded structure has often been explained as due to rhythmic precipitation after the manner of Liesegang's ring experiment with gelatine. A more feasible explanation, based on Nutting's research, is that the bands of iron oxide and also the bitumen were adsorbed on the surface of the silica gel as it grew. An alternative explanation is that a vug occurred inside the solidified chert and was later filled with bitumen, but this appears less probable than the first explanation.

Finally, there are oölites in which some inner coatings are bitumen-stained, and outer coatings and the matrix are clear. This could have happened as the

oölites formed, or there may have been selective adsorption by particular bands afterward. This is more a matter of general interest than of direct evidence on the point under discussion, but it is suggestive of the presence of oil when the limestone was forming.

Conclusive evidence is not easily obtainable, but as this adsorbed bitumen can be found throughout both Mississippian and Devonian limestones, the

Fig. 8

circumstantial evidence, together with the specific evidence quoted, suggests that oil was already present in pre-Jurassic time.

SOURCE OF OIL

After extensive research on limestone oil fields W.V. Howard[14] considers that oil accumulations (under conditions similar to those revealed in the Turner Valley field) indicate generation of the oil within the reservoir itself long after the secondary porosity had been formed. Howard[15] states "Any oil previously formed would be flushed from the formation while the continuous porosity was being developed."

Nutting,[16] as a result of experimental research, has found that when oil is adsorbed on to activated silica, carbonates, *et cetera,* it forms a surface of attach-

[14] W. V. Howard, "Accumulation of Oil and Gas in Limestone," *Problems of Petroleum Geology* Amer. Assoc. Petrol. Geol. (1934), pp. 365–75.

[15] *Ibid.*, p. 367.

[16] P. G. Nutting, *op. cit.*

ment for other oil, and this is not easily displaced by water, excepting in the larger pores.

In the Turner Valley oil field the evidence indicates that oil was already in existence in the limestone while the reservoir was being formed. Presumably this was generated from material deposited with the limestone. The assumption that a second generation of oil occurred long after the secondary porosity had been formed is not entirely convincing.

Outcropping limestones from which oil is still seeping after very long exposure of the rock to meteoric waters indicate that although some oil may have escaped from a limestone beneath unconformable sediments, much of it could have been retained. An example of this is the Presqu'ile dolomite of Great Slave Lake quoted by Hume.[17]

Whether oil and gas generated in the Fernie (Jurassic) shales could penetrate downward into the porous lenticles in the limestone under heavy pressure is open to question. It would appear that sandstones above the source beds would offer an easier way of escape from the shale.

Moreover, the fact that drilling has to be carried some little distance into the limestone before reaching production indicates that an impervious shell exists, as is the case in other similar fields where, in some cases, solid anhydrite forms a cap rock.

HISTORY

At this stage the evidence appears insufficient to permit of definite conclusions concerning the time and manner of formation and accumulation of Turner Valley oil and gas. There is plenty of opportunity to discover more evidence, but the following is a tentative reconstruction of events leading to the formation of the present limestone reservoir based on the information available.

1. As deposition of the limestone progressed, silica carried in meteoric waters was also coagulated and deposited, and sea water produced a limited amount of dolomitization. After consolidation the limestone retained some primary porosity, and there is good reason to suspect that oil-forming conditions were already present at this stage. The environment favorable for deposition of dolomite and anhydrite consists of warm seas, steadily shrinking through dessication. Oölites are also characteristic of such conditions, coupled with agitation from escaping gas, or by wave action.

2. After consolidation the limestone lay at or above sea-level for a considerable period. Meteoric waters, carrying colloidal silica, derived from the westerly landmass, circulated in the top of the limestone and down to the level of the water table. Incidentally, in this connection Versluys[18] states that fresh water under a small head can circulate in, and alter, limestone lying beneath the sea.

[17] G. S. Hume, "Oil and Gas in Western Canada," *Canada Geol. Survey Econ. Geol. Ser. 5* (1933).

[18] J. Versluys, "Subterranean Water Conditions in the Coastal Regions of the Netherlands," *Econ. Geol.*, Vol. 26 (1931), pp. 65–95.

3. By leaching and redeposition of the more soluble calcite, and possibly also of dolomite, the Altered zone was formed. In general the results were: (a) an increase in porosity in some parts; (b) an increase in dolomitization in some parts by removal of surplus calcium carbonate; (c) an increase in calcium carbonate in some parts by secondary infilling; and (d) replacement of calcite and/or dolomite by secondary silica.

Whilst these changes were taking place oil was already present in the limestone, and may have been prevented from complete dissipation by the adsorptive action already referred to. Concentration probably occurred much later after further compaction under the load of Mesozoic sediments, and folding and faulting had produced favorable structures.

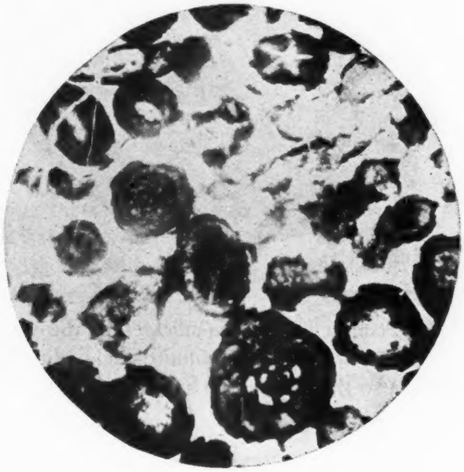


FIG. 9

OTHER PETROGRAPHIC ITEMS OF INTEREST

Thin sections of more general interest and outside the scope of the previous argument are here described.

The matrix of an oölite from the C. D. & P. well (Fig. 9) consists of crystalline anhydrite with the anhydrite crystals biting into the oölite grains. Veinlets fill cracks in the rock. Where these cross the matrix they disappear in the anhydrite of the matrix, and where they cross an oölite grain they are of calcite. It appears that anhydrite has replaced a calcareous matrix.

Fluorite has been noted in small amount throughout the thin sections. In the C.D. & P. well there are small veins of this material. So far the writer has not observed this mineral in limestone samples from wells in the Plains region.

It has been reported from the outcrop of the Rundle limestone. In Figure 10 fluorite occurs intercrystallized with quartz. This may indicate fluorine emanations from depth, or possibly fluorides could be carried in meteoric waters which

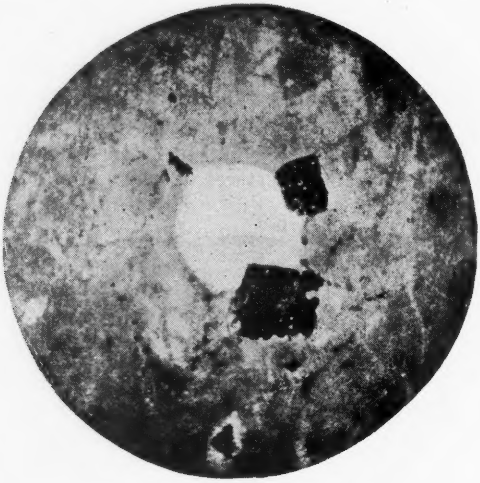


FIG. 10

had previously been in contact with fluo-silicates in the western landmass. It may be of some interest to note that hydrofluoric acid is one of several reagents which will activate silica so that it adsorbs bitumen.

PROBLEMS

This study represents only a small beginning, and it is hoped that the opportunity to widen the scope and search for new evidence will be taken up. In this connection the following are some of the problems which naturally arise and call for solution.

1. The distinction between primary porosity and that related to erosional processes
2. The finding of reliable stratigraphical markers in the Mississippian limestone from well samples
3. What is the lateral extent of secondary porosity? For example, is it related to shore-line or other conditions?
4. Can porous zones in Turner Valley be correlated with those in other areas?
5. Do argillaceous limestones in general resist alteration by circulating waters?
6. Are these any more erosional unconformities which might furnish suitable reservoir conditions?

Doubtless many additional questions will arise in the minds of those continuing this research. Whether we shall be able to find all the answers, or enough answers to formulate guiding principles in the search for new fields, remains for the future, but in the writer's opinion the possible economic value of further inquiry certainly would justify the effort required for intensive research.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 8 (AUGUST, 1945), PP. 1169-1188, 7 FIGS.

GROUND-WATER GEOLOGY OF CAMP POLK AND NORTH CAMP POLK, LOUISIANA[1]

JOHN C. MAHER[2]
Tulsa, Oklahoma

ABSTRACT

Camp Polk and North Camp Polk are underlain by poorly consolidated fluviatile and brackish-water sediments of the Miocene series, which are at or near the surface throughout central and northern Vernon Parish. These formations, which dip southward at a rate of 50 to 100 feet per mile, consist chiefly of alternating loose sands, sandy shales, and tough clays with a few hard sandstone and lime-nodule horizons. The most important water-bearing sands, referred to in this article as the "A," "B," "C," and "D" sands or sand-zones, are found at depths of 600 to 1,450 feet. The "B" sand is the only water sand developed at both cantonments. The "A" and "B" sands are found at depths of 600 and 900 feet, respectively, at the south camp; the "B," "C," and "D" sands are found at 600, 1,200, and 1,450 feet, respectively, at the north camp. These sands are recharged principally by rainfall in the hills of northern Vernon Parish. The hardness of the water ranges from very soft to medium hard.

A total of nine supply wells are pumped part-time at the south camp. Two of these wells draw from the "A" sand, the remainder from the "B" sand. At the north camp there are also nine supply wells that are used part-time. Five of these wells draw from the "B" sand, three from the "C" sand, and one from the "D" sand. The combined pumpage at the two camps is several million gallons a day. Pumping tests of wells at both camps indicate that both the "C" and "D" sands in the existing wells are better aquifers than the "A" and "B" sands.

INTRODUCTION

Camp Polk, constructed in 1941, is about 6 miles southeast of the town of Leesville in the Kisatchie National Forest of central Louisiana (Fig. 1). The cantonment is situated in rolling hill land sparsely covered with second growth timber. The elevation of the land surface ranges from about 250 to almost 400 feet above mean gulf level. About 3 miles to the northeast is North Camp Polk, an addition built in 1942, which has a similar topographic situation. Leesville, the parish seat of Vernon Parish, is the nearest town and has a population of 4,000.

The climate in this area is rather mild. The temperature seldom is less than 30°F. in the winter or more than 95°F. in the summer. The United States Weather Bureau has stations for collecting climatological data at Camp Polk, Leesville, and DeRidder. The average rainfall in this area is about 54 inches a year. The period of least rainfall usually includes the fall months.

Field investigations in the Camp Polk area were begun in 1941 by the writer in connection with the construction of Camp Polk and were continued in 1942 when North Camp Polk was built. Detailed pumping tests were made by W. F. Guyton and W. J. Drescher of the Geological Survey in March, 1943, after the completion of North Camp Polk and, on July 1, 1943, a comprehensive water-supply report[3] on the two cantonments was submitted to the War Department.

[1] Manuscript received, April 18, 1945. Published by permission of the War Department and the director of the Geological Survey.

[2] Associate geologist, Geological Survey, United States Department of the Interior.

[3] J. C. Maher, W. F. Guyton, W. J. Drescher, and P. H. Jones, "Ground-water Conditions at Camp Polk and North Camp Polk, Louisiana," unpublished report. (1943).

The portion of this report containing data that might be useful in future geologic work in the area has been used in this article. Detailed maps and pumpage figures have been withheld in accordance with security regulations. Electric logs, drillers' logs, water-level records, and mechanical analyses of sands, all of which are too lengthy for this type of publication, are on file at the offices of the Geological Survey in Baton Rouge, Louisiana and Washington, D.C.

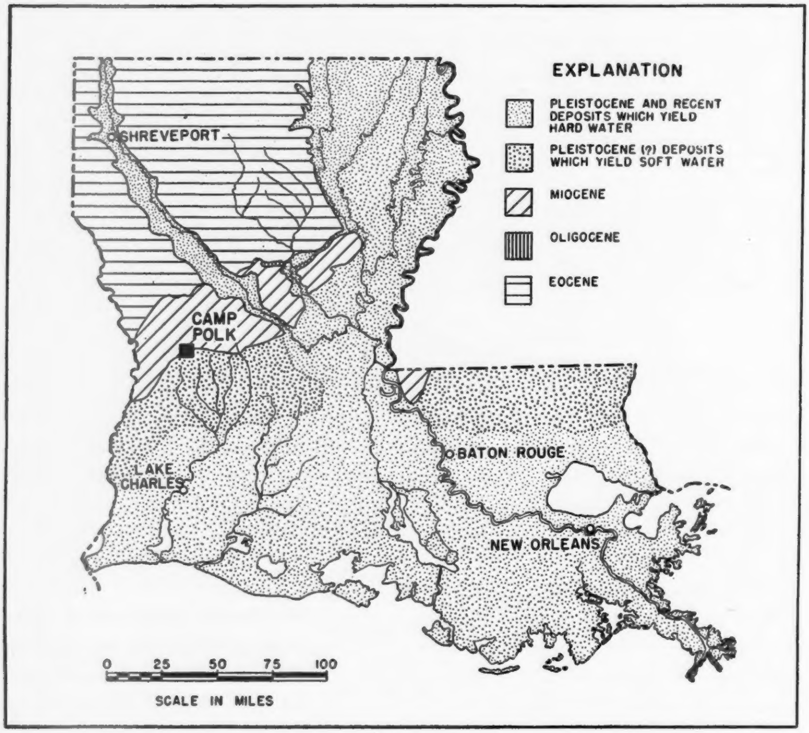


FIG. 1.—Generalized geologic map of Louisiana showing location of Camp Polk area.

These investigations were made at the request and expense of the Corps of Engineers, United States War Department. Acknowledgment is made of the aid and coöperation of the personnel of the Corps of Engineers, particularly F. H. Fowler who was responsible for the coöperative arrangements between the Corps of Engineers and the Geological Survey, and Major E. S. Thomas, Major E. H. Le Blanc, and W. H. Bates of Camp Polk who facilitated the field work. T. B. Stanley, Jr., collected samples and drilling data for the wells at North Camp Polk. P. H. Jones assisted in the preparation of the illustrations. The writer is

indebted to O. E. Meinzer and V. T. Stringfield of the Geological Survey for reviewing this article, and to the War Department for permission to publish it.

OUTLINE OF GROUND-WATER CONDITIONS

A portion of all the rain that falls on the surface of the earth percolates downward through surficial materials until it finally reaches a zone in which the rock is completely saturated. The gently undulating upper surface of this saturated zone is known as the *water table*. The water table conforms roughly to the topography, generally being closer to the surface in the low land than in the hill land. The movement of the ground water is always in the downslope direction of the water table toward the lakes and streams where the ground water may emerge at the surface. Under water-table conditions the water in wells does not rise in the well casing. Water-table conditions are present in the shallow rural wells used on the farms of this area.

In some regions, such as central Louisiana, inclined permeable formations are underlain and overlain by relatively impermeable beds. Water falling as rain upon the beveled outcrop or intake areas of these permeable formations percolates downward until it becomes confined between the inclined impermeable beds. Further percolation is restricted to lateral or downdip movement in the conduit and the water is under what is termed *artesian pressure*. The water in a well penetrating this reservoir at any locality that is lower than the intake area will rise in the casing. Such a well may be called an *artesian well* whether or not the pressure is sufficient to cause it to overflow at the surface. The principal industrial and municipal water supplies of central Louisiana are derived from artesian wells that do not flow. All the deep wells at Camp Polk are classed as non-flowing artesian wells.

GEOLOGIC FORMATIONS AND THEIR WATER-BEARING PROPERTIES

Louisiana is a part of the Gulf Coastal Plain, which was formed by the near-shore deposition of sediments during the Cenozoic era. The older Eocene sediments deposited during the early part of the era are found at the surface in northern Louisiana, with progressively younger formations overlying them toward the Gulf of Mexico (Fig. 1). In general, these formations dip toward the south and thicken considerably down the dip. The rate of dip ranges from 20 to more than 200 feet to the mile.

MIOCENE SERIES

Outcrop and lithology.—The oldest formations penetrated in drilling water wells in Camp Polk and vicinity are the poorly consolidated fluviatile and brackish-water sediments of the Miocene series cropping out in the hill land of central and northern Vernon Parish. These formations, which dip southward at a rate of 50 to 100 feet per mile, consist chiefly of alternating loose sands, sandy shales, and tough clays with considerable bentonitic material. In general, the

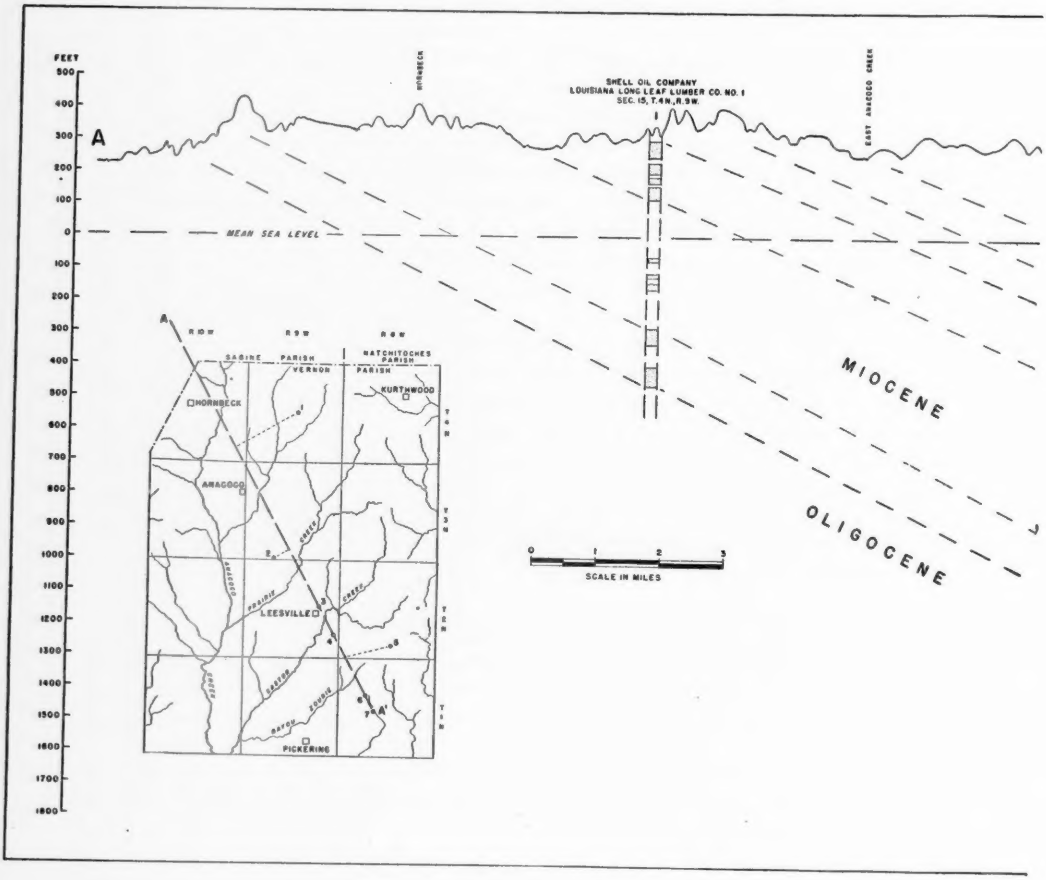
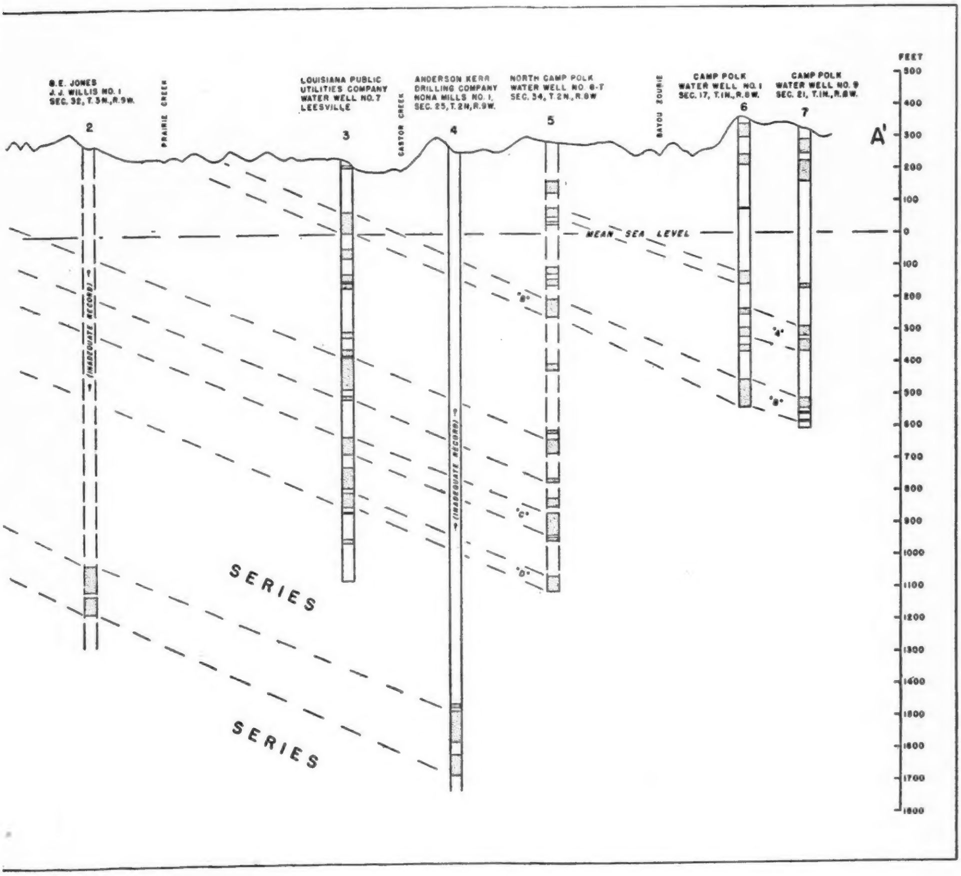


FIG. 2.—Regional cross section from



Hornbeck to Camp Polk, Louisiana.

TABLE I

RECORDS OF WELLS DRILLED AT CAMP POLK AND NORTH CAMP POLK. NUMBERS DESIGNATING WELLS ARE THE SAME AS THOSE THROUGHOUT THE REPORT.

Camp No.	Location	Depth of Well (Feet)	Length and Diameter of Surface Casing (Feet-Inches)	Length and Diameter of Well Casing (Feet-Inches)	Depth to Top of Screen (Feet)	Length of Screen (Feet)	Depth to Top of Sand (Feet)	Thickness of Sand (Feet)	Water Level Below Measuring Point (Feet)	Date of Measurement	Measuring Point: Above Mean Sea-Level (Feet)	Measuring Point: Above Land Surface (Feet)	Measuring Point: Descrip. of Measuring Point	Yield of Well on Completion (G.P.M.)	Specific Capacity	Temperature °F.	Use	Remarks
CAMP POLK																		
1	300′ NE of intersection, Miss. & Georgia Aves.	901	None	849′-4½″	849	42	818	80	193.53	2/11/41	368.5	1.1	Top of casing	26			Test	Electric survey. Casing pulled.
2	Location abandoned.																	
3	10th & Georgia Aves.	904	None	858′-4½″	858	42	833	66	167.00	1/20/41	338.1	1.1	Top of casing	45	0.8		Test	Electric survey 1/15/41. Well buried.
4	NW SW Sec. 17, T. 1 N., R. 8 W., on road to water tower	908	None	821′-6″	821	24	836	24	171.00	2/2/41	345.8	1.0	Top of casing	192	1.9	78	Temporary	Electric survey 1/27/41.
4A	NW SW Sec. 17, T. 1 N., R. 8 W., 150′ E. of well 4	856	None	830′-4½″	830	20	833	23	195.33	11/24/41	348.1	1.0	Top of casing				Test	
5	10th & Alabama Aves.	912	834′-18″	847′-10″	847	60	839	68	173.0	2/23/41	341.8	1.0	Top of casing	374	4.5	78	Supply	36″ under-reamed gravel-packed well.
6	11th & Miss. Aves.	892	813′-8″	110′-6″	837	40	822	55	162.8	3/6/41	333.5	1.0	Top of casing	257	3.8	78	Supply	Electric survey 3/2/41
6A	11th & Miss. 200′ N of well 6	899	822′-18″	842′-10″	842	50	818	79	170.4	4/15/41	334.0	1.0	Top of casing	450	8.9	78	Supply	36″ under-reamed gravel-packed well.
7	1200′ W of Miss. Ave. on La. Ave.	925	840′-18″	853′-10″	853	50	841	81	149.7	5/22/41	304.5	1.0	Top of casing	305	4.7	78	Supply	36″ under-reamed gravel-packed well.
8	300′ SW of intersection Colorado & Wyoming Aves.	678	595′-8″	114′-6″	640	35	605	71	145.3	2/26/41	306.7	1.0	Top of casing	215	5.2	72	Supply	Electric survey 2/11/41.
8A	Colorado & Wyoming Aves., 100′ E of well 8	920	840′-18″	870′-10″	870	50	870	89	154.7	4/9/41	320.0	1.0	Top of casing	425	15.0	78	Supply	36″ under-reamed gravel-packed well
9	700′ E of pumping station across RR.	930	613′-18″	639′-10″	621	50	614	62	154.8	6/2/41	317.2	1.0	Top of casing	387	3.4	72	Supply	36″ under-reamed gravel-packed well.
10	Location abandoned																	
11	1650′ N of pumping plant along RR.	915	819′-18″	835′-10″	835	50	819	69	169.7	5/3/41	335.7	1.0	Top of casing	411	14.9	78	Supply	36″ under-reamed gravel-packed well.

12	3575′ N of pumping plant along RR.	895	810′-18″	828′-10″	827	50	810	67	170.6	6/25/41	334.3	1.0	Top of casing	480	13.5	78	Supply	36″ under-reamed gravel-packed well.
NORTH CAMP POLK																		
1T	9th St. between E & F Aves.	600	None	570′-4″	572	15	562	38	194.40	6/11/42	355.5	6.2	Top of casing	44	3.8	72	Test	Casing pulled.
2T	Between 9th & 10th Sts. on H Ave.	800	None	582′-4″	582	15	554	65			323.8		Land surface	35		72	Test	Casing pulled.
3T	10th St. and K Ave.	801	None	None	None						348.7		Land surface				Test	Casing pulled. Sand to thin.
4TS	225′ N of well 1T	800	None	552′-8″	552	66	551	73	184.55	5/18/42	345.5		Land surface	370	8.2	72	Supply	Temporary stand-by well.
5T	9th St. & K Aves.	1000	None	470′-4″	470	15	455	32	169.05	6/1/42	344.6	5.5	Top of casing				Abd.	Tested sand at 455 feet.
6T	8th St. & C Ave.	610	None	562′-4″	562	15	520	86	171.66	6/1/42	332.1	4.4	Top of casing				Test	
7T	1500′ N of well 4TS	1275	None	1213′-4″	1213	21	1171	99	138.64	6/8/42	347.1	5.5	Top of casing				Test	Casing pulled.
8T	Sec. 34, T. 2 N., R. 8 W., 8th St. & A Ave.	1500	None	1420′-4″	1420	15	1407	45	151.40	6/18/42	342.0	4.0	Top of casing				Test	Casing pulled.
2PS	Between 9th & 10th Sts. on H Ave.	617	543′-12¾″	105′-8″	543	58	545	67	171.0	12/17/42	324.1	1.0	Top of pump base	220	3.1	72	Supply	27″ under-reamed gravel-packed well.
2PD	Between 9th & 10th Sts. on H Ave.	1233	None	1170′-12¾″	1170	58	1174	58	120.0	12/18/42	324.3	1.0	Top of pump base	358	9.0	82	Supply	No gravel pack.
4PS	About 600′ W of well 4T	613	542′-12¾″	106′-8″	545	66	542	64	190.0	1/2/43	338.1	1.0	Top of pump base	240	14.1	73	Supply	27″ under-reamed gravel-pack well.
6PS	8th St. & C Ave.	600	532′-12¾″	107′-8″	532	66	536	64	175.36	8/20/42	329.6	1.4	Top of pump base	339	15.6	72	Supply	27″ under-reamed gravel-pack well.
6PD	8th St. & C Ave.	1307	1171′-12¾″	221′-10″	1171, 1240	40, 40	1184, 1225	80	122.0	1/14/43	329.25	1.0	Top of pump base	245	3.1	82	Supply	No gravel-pack. Two 10″ screens.
7PD	1500′ N of well 4TS	1279	None	1189′-12¾″	1191	86	1187	92	137.0	1/8/43	340.6	1.0	Top of pump base	434	18.9	82	Supply	No gravel pack.
8PS	8th St. & A Ave., 100′ SE. of well 8T	604	541′-12¾″	115′-8″	552	50	543	52	199.5	3/20/43	339.6	1.0	Top of pump base	215	10.2	82	Supply	27″ under-reamed gravel-pack well.
8PD	8th St. & A Ave., 100′ SE. of well 8T	1456	1207′-12¾″	200′-8″	1407	43	1407	49	143.0	3/20/43	338	11.0	Top of pump base	308	3.7	84	Supply	No gravel pack. 12″ screen set at 1288′ sealed off, and 8″ liner set from 1207′ to 1407 after well failed to yield sufficient water.

sands are fine-grained and very irregular in texture, thickness, and extent, though the continuity of the principal water sands is apparent from subsurface study (Fig. 2). Lime nodules, a few fossils, and some hard thin sandstones cemented with opaline silica are found in the section. The sediments are reported to increase in thickness from 3,000 feet in Vernon Parish to at least 12,000 feet in southern Louisiana where they are marine in character.[4]

The Miocene series in Louisiana is divided by some geologists into two formations, the Catahoula (older) and the Fleming (younger). A controversy over the exact line of demarcation, supposedly based on the calcareous nature of the upper formation (Fleming), and the sandy character of the lower formation (Catahoula), has existed for many years. The principal fossil horizon of the upper formation, a zone in the Fleming containing the gastropod *Potamides matsoni* and an assemblage of pelecypods, gastropods, foraminifera, and ostracods, was not found at Camp Polk. As the lithology of the entire Miocene section is very similar and the arbitrary subdivision of the series is of little or no value in this water-supply investigation, no use of formal names is made in this report.

Structural conditions.—The regional geologic structure of the Camp Polk area is shown in Figure 2, a geologic cross section from the outcrop of the basal Miocene sands north of Hornbeck to Camp Polk. The beds dip southeastward from the Kisatchie Hills north of Leesville at a rate of 50 to 100 feet per mile. A steepening of the dip with depth in the section, a thickening of the sediments southward, and the irregular nature of the sand bodies are apparent in this cross section. Such conditions are generally found in non-marine deposits like these. The most persistent beds in this area are the principal water sands or sand zones at North Camp Polk, and the basal Miocene sands. Hard rock beds and layers of lime nodules offer some aid in making local correlations.

Water sands.—The water sands of the Miocene series furnish the principal industrial and public water supplies in Vernon Parish. The supplies include Camp Polk, North Camp Polk, Big Oaks camp, Leesville, Hornbeck, Anacoco, Kurthwood, and Simpson. However, the pumpage at Camp Polk and North Camp Polk constitutes about 90 per cent of the total amount of water used in the parish. The records of wells at these large cantonments are given in Table 1.

The most important water-bearing sands of the Miocene series in this area are shown on Figure 2 as "A," "B," "C," and "D" sand zones. All the sands range considerably in thickness and permeability. The sand grains are ordinarily not well rounded or well sorted, and tend to pack tightly. It has been noted that numerous sands at the surface are cemented with white opaline silica commonly forming hard rock layers. These hard rock layers, with the exception of a few of the quartzitic layers, become soft, loose sand when constantly saturated with water. Thus, many hard rock layers appear on the outcrop that can not be traced in bore holes. The chemical quality of the water suggests that some

[4] R. N. Welch, "Geology of Vernon Parish," *Louisiana Dept. Cons. Geol. Bull. 22* (1942), p. 37.

natural softening of the water has occurred. The white opaline silica, possibly related to bentonite in composition, may cause such softening of water in some of the sands. In general, the water sands in this area are thicker, coarser, and more permeable than those developed in the deep wells at Camp Livingston and Camp Claiborne farther east, in Rapides Parish.

Figures 3, 4, 5, and 6 show the water sands that have been developed at Camp Polk and North Camp Polk. The "A" sand zone, termed the "600-foot" sand, is present at depths of 605 to 676 feet along the south line of wells in Camp Polk (Fig. 5) where it ranges from about 50 to 70 feet in thickness. This sand thins considerably from the south wells to the north wells where it is represented by two thin sand members (Figs. 3 and 4). Correlation of the "A" sand from Camp Polk to North Camp Polk (Fig. 2) was not attempted, as it apparently is too thin and fine-grained to be considered as a source of water in North Camp Polk. Its outcrop would be expected in the vicinity of Castor Creek between the camps and Leesville. Mechanical analyses of sand samples from a depth of 630–660 feet in well 6 at Camp Polk indicate that, even in the area where the sand is best developed, it is poorly sorted and rather fine-grained. Coefficients of transmissibility[5] obtained from pumping tests made by Guyton and Drescher[6] indicate that this sand is the poorest aquifer developed at the camps.

The "B" sand-zone crops out in the hills just north of Leesville along Prairie Creek and supplies water to springs feeding this stream. It is well exposed in the railroad cut of the Kansas City Southern Railroad and in the town dump, both of which are in the SE. $\frac{1}{4}$ of Sec. 10, T. 2 N., R. 9 W., about $1\frac{1}{2}$ miles north of Leesville. It is also exposed in a road cut on Louisiana State Highway 39 in the SE. $\frac{1}{4}$ of Sec. 11, T. 2 N., R. 9 W. Dissected remnants of this sand mantle the hills for several miles along this highway, but the effective width of outcrop for recharge is limited to a strip about 1 to $1\frac{1}{2}$ miles wide extending from the southwest to the northeast in the Leesville region.

The "B" sand-zone yields water to three "180-foot" wells in Leesville, five "600-foot" wells in North Camp Polk, and eight "900-foot" wells ln Camp Polk. It ranges in depth from 520 to 624 feet in North Camp Polk, and from 810 to 930 feet in Camp Polk. A minimum thickness of 23 feet was found in well 4 at Camp Polk and a maximum thickness of 86 feet in well 6T at North Camp Polk. The average thickness in the cantonment area is about 65 feet.

The irregular character of this sand-zone is apparent from the logs of wells 4 and 9 in Camp Polk and wells 3T and 5T in North Camp Polk, which record considerable sandy clay and shale separating thin members of sand in the "B" zone. The discrepancies between thicknesses of this sand as shown on the logs of adjacent wells 2PD and 2PS are due to the driller's failure to record carefully the upper beds in well 2PD which had already been tested by wells 2T and 2PS.

[5] C. V. Theis, "The Significance and Nature of the Cone of Depression in Ground-Water Bodies," *Econ. Geol.*, Vol. 33 (1938), pp. 889–902.

[6] J. C. Maher, W. F. Guyton, W. S. Drescher, and P. H. Jones, *op. cit.*, Table 15.

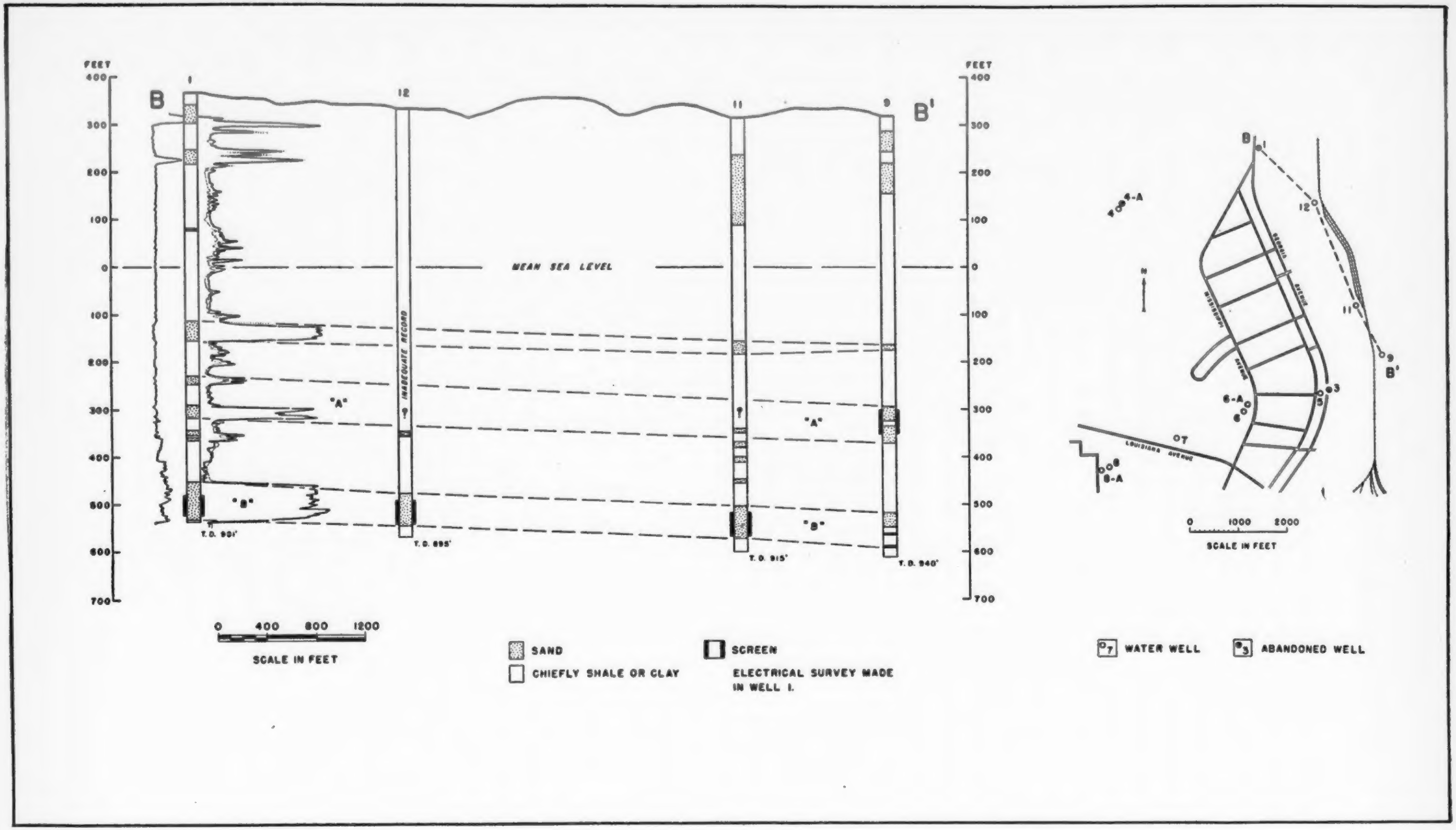


FIG. 3.—Geologic cross section across Camp Polk from north to south along line *BB'*.

FIG. 3.—Geologic cross section across Camp Polk from north to south along line *BB'*.

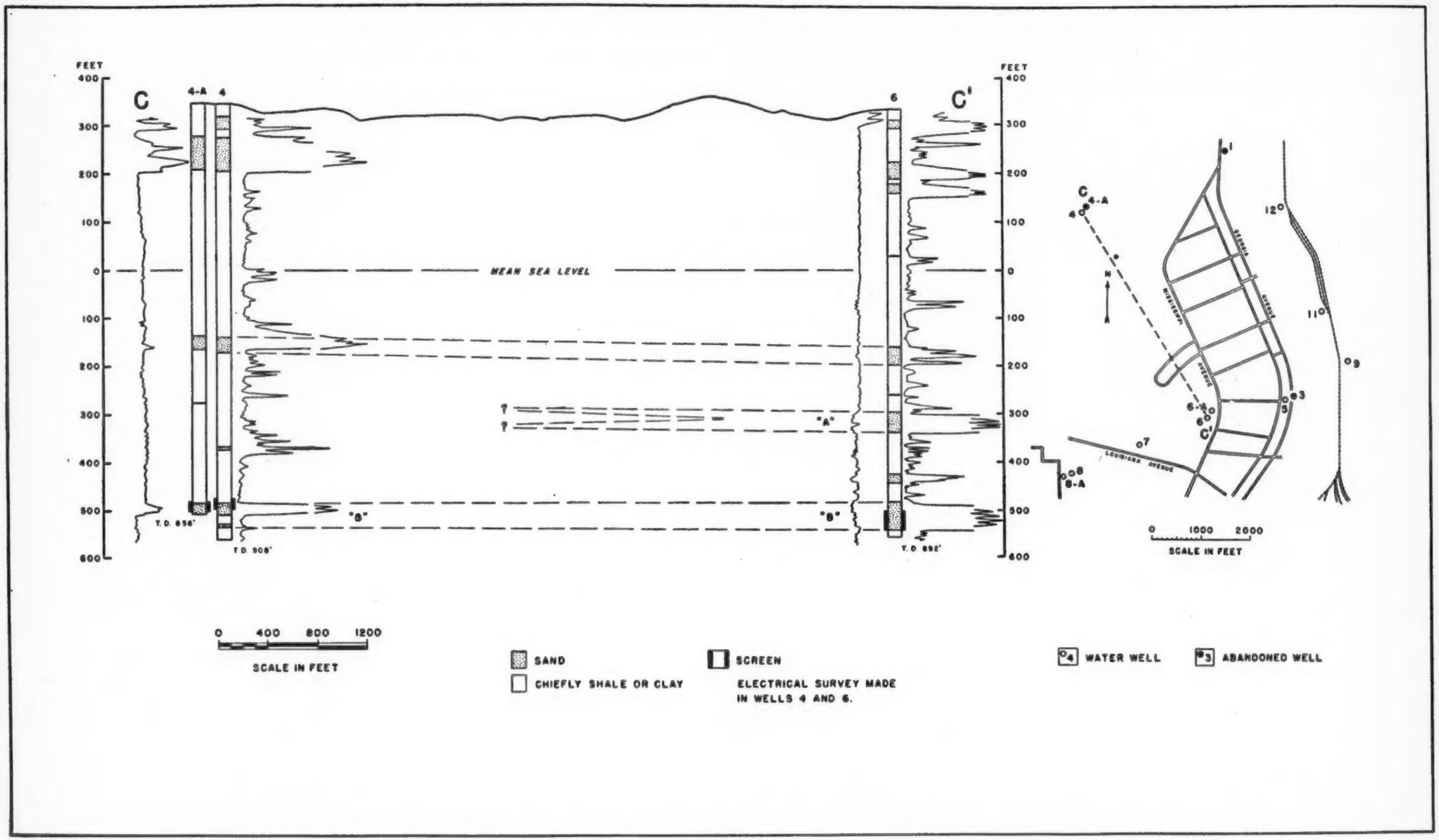


FIG. 4.—Geologic cross section across Camp Polk from north to south along line *CC'*.

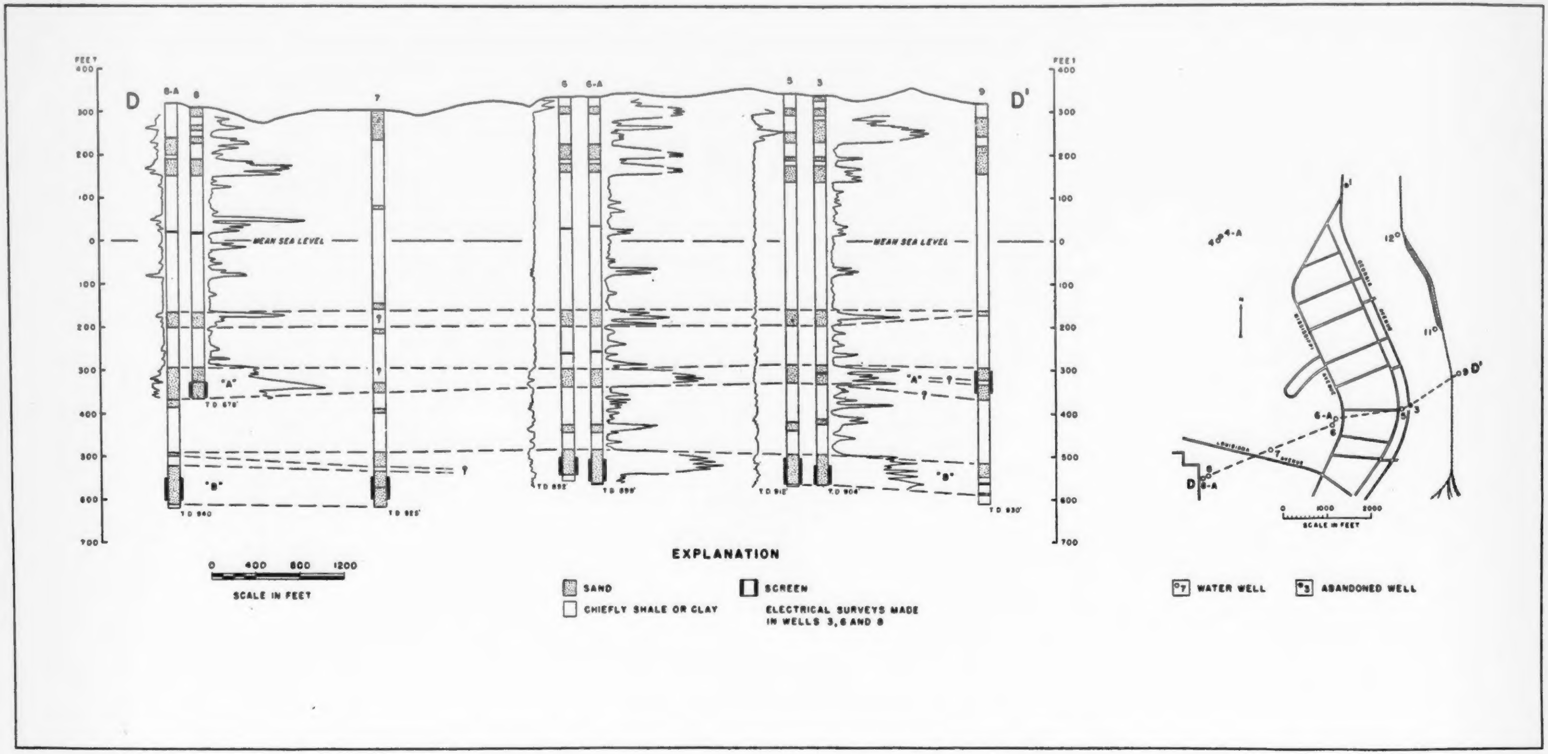


FIG. 5.—Geologic cross section across Camp Polk from west to east along line *DD'*.

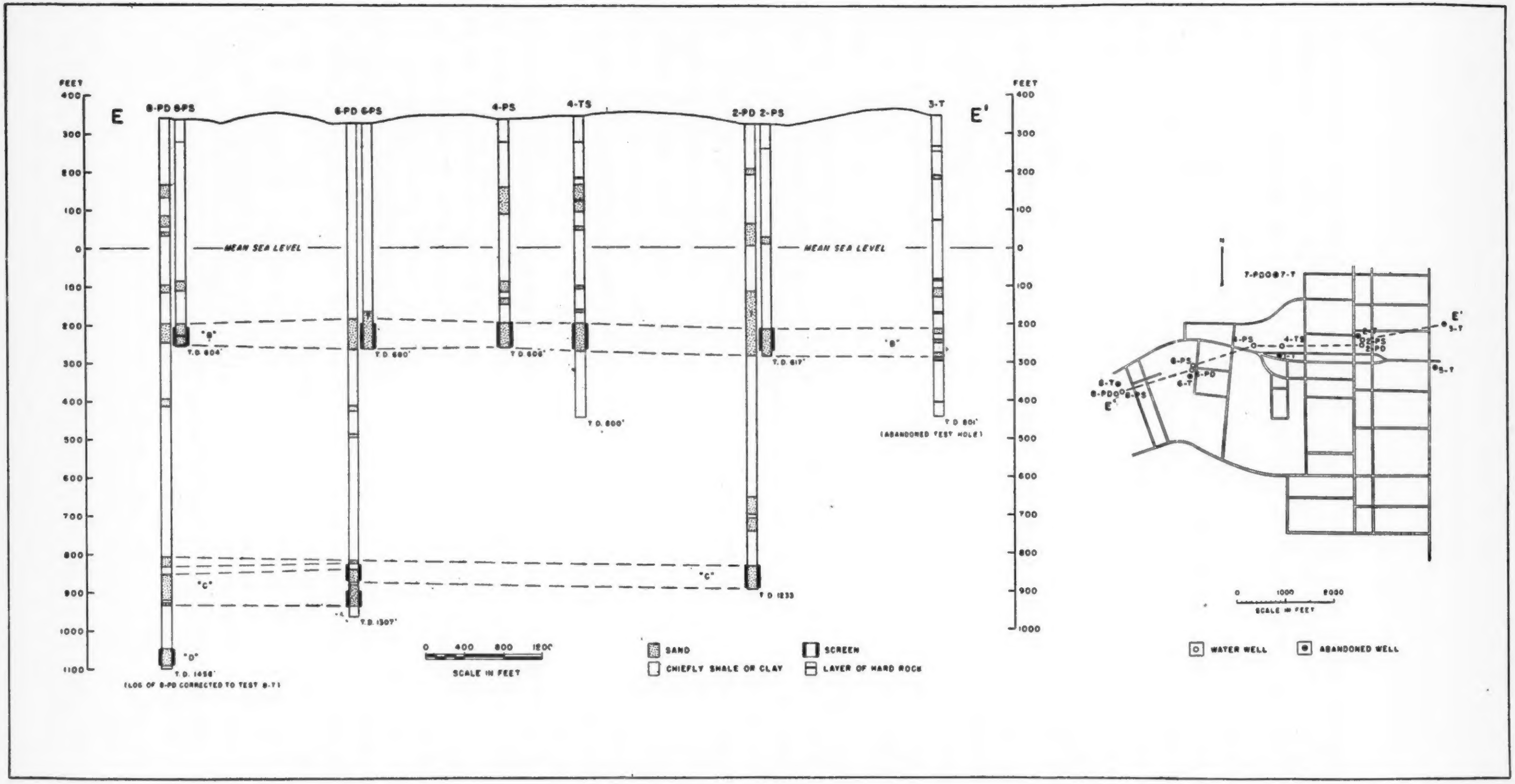


FIG. 6.—Geologic cross section across North Camp Polk from west to east along line EE'.

This zone is the most important aquifer in this area from the standpoint of development, but ranks below both the "C" and "D" sands in comparison of respective average coefficients of transmissibility determined by pumping tests.

The "C" and "D" sand zones are parts of a sequence of sandy beds that can be traced from North Camp Polk, where they are present at depths of 1160 to 1450 feet, to Hornbeck, where they cap the steep hills (Fig. 2). Numerous clear brooks and springs in the Hornbeck area derive their water from these sands.

The "C" sand zone is probably represented at the surface by the fine to coarse sand exposed along U.S. Highway 171 about 2 to 3 miles southeast of Hornbeck in the NW. ¼ of Sec. 26, T. 4 N., R. 10 W. Some of the sand is well cemented forming hard sandstone layers, a few of which are sedimentary quartzites. Thin stringers of black-chert gravel are found in the sand at this locality. Owing to the mantle of surficial materials, the dissected nature of the topography, and the presence of similar Miocene sands closely underlylng the "C" sand, the width of the outcrop could not be accurately determined, but it probably has an effective width for recharge of about one mile.

This sand ranging from 58 to 92 feet in thickness yields water to three wells (wells 2PD, 6PD, and 7PD) in North Camp Polk. It was also developed in well 8PD but was cased off and the well drilled deeper when it continued to yield sand. Judged by the coarse texture of samples from the near-by test well 8T, the failure of this well may have been due to improper screening or development. Pumping tests of wells 2PD, 6PD, and 7PD showed that the "C" sand has the highest average coefficient of transmissibility of the four sands developed at the camps. None of the wells at the south camp has been drilled deep enough to penetrate this sand zone, which might be expected there at depths of 1450 to 1600 feet depending on the relative location of the well. Owing to the general irregularity of the Miocene sands, however, the thickness and texture of the sand may be quite different at the south camp.

The "D" sand zone, penetrated at a depth of 1407 to 1456 feet in wells 8PD and 8T at North Camp Polk, crops out at Hornbeck. Samples of this sand from well 8T show it to be very coarse in texture. The results of a pumping test at well 8PD show that this sand has a coefficient of transmissibility somewhat less than that of the "C" sand but larger than that of the "B" sand. However, the data available from this one location are not adequate to judge the water-bearing properties of the sand in the whole area. This sand, or its equivalent, might be expected at depths of 1650 to 1800 feet at the south camp, but no predictions of its water-bearing characteristics are warranted.

The basal sands of the Miocene series are exposed in a railroad cut in the NW. ¼ of Sec. 8, T. 4 N., R. 10 W., about 2 miles north of Hornbeck on U.S. Highway 171. These sands contain fresh water for some distance south of Hornbeck, but probably yield salt water in the vicinity of Camp Polk. An electric log of an oil test in the SE. ¼ of Sec. 9, T. 1 S., R. 8 W., about 4 miles southeast of

Camp Polk, recorded the base of the Miocene at a depth of 3568 feet and revealed highly mineralized water in the basal sands.

Recharge of water sands.—The water sands of the Miocene series are separated by thick beds of impermeable shale and clay, which confine the movement of the ground water to a lateral or downdip direction. The ground water is supplied from areas of higher altitude where the sands are at or near the surface. For that reason, the water in the Miocene sands is under artesian pressure except in the outcrop area where recharge occurs. The principal recharge area of the entire Miocene series is in the highlands of the Kisatchie Wold, which extends across central Louisiana. The recharge is obtained partly from rain falling directly upon the exposed Miocene sands, partly from the transmission of water through younger surficial materials (Pleistocene and Recent) into the Miocene sands, and, perhaps, partly from surface streams.

The recharge of water to the Miocene sands supplying the Camp Polk area is obtained from rainfall upon the water sands exposed in their respective outcrop areas, which extend as narrow strips of sandy soil and rock across Vernon Parish from southwest to northeast. Most of the recharge is accomplished by direct percolation of rain into the water sands, as little or no surficial material overlies the sands to prevent easy access to them. Field examination has revealed that the surface streams generally flow over clay beds and receive water from springs originating in the Miocene sands on the hills. This indicates that little or no recharge from streams occurs in this region.

Some idea of the distances from Camp Polk to the nearest recharge areas of the different sands may be obtained from Figure 2. The "A" sand, which is very irregular, probably crops out along Castor Creek, which is about 4–5 miles from Camp Polk. The "B" sand covers the surface of the narrow strip of hills (1–1½ miles wide) along Prairie Creek, which is 8–10 miles from Camp Polk. The "C" and "D" sands cap the steep hills in the latitude of Hornbeck, about 20 miles north of Camp Polk.

Quality of water.—Twenty-three samples of water from the wells at Camp Polk and North Camp Polk were examined with reference to their chemical character in the Water Resources Laboratory, Washington, D. C. The results of the preliminary examinations are shown in Table II and those of the complete chemical analyses in Table III. The determinations made in the preliminary examinations were bicarbonate, sulphate, chloride, nitrate, fluoride, and the total hardness as calcium carbonate. In the complete chemical analyses the following were determined: silica, iron, calcium, magnesium, sodium, potassium, bicarbonate, sulphate, chloride, fluoride, nitrate, the total dissolved solids, and total hardness as calcium carbonate. The results are expressed in parts per million of the radicles determined but may be converted to grains per United States gallon by multiplying by 0.058 or dividing by 17.12.

In general the analyses show a range in hardness of the water from soft (22 parts per million) to moderately hard (207 parts per million). This wide range

TABLE II

PRELIMINARY EXAMINATION OF WATER SAMPLES FROM WELLS AT CAMP POLK AND NORTH CAMP POLK

Well No.	Date of Collection	Depth (Feet)	(Parts per Million) Bicarbonate (HCO_3)	Sulphate (SO_3)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Hardness $CaCO_3$
5	2/25/41	907	120	5	14	0.1	—	45
6	4/13/42	892	118	6	14	.1	—	36
6A	1/28/43	897	126	5	17	—	—	36
7	4/13/42	903	142	6	26	.4	—	45
8	2/2/43	665	236	3	14	.4	—	93
8A	4/13/42	920	124	8	23	.2	—	33
9	11/24/41	689	241	1	15	.2	—	45
11	11/24/41	888	105	7	20	.4	—	51
12	4/13/42	877	104	5	16	.3	—	48
1T	5/9/42	594	230	5	22	.0	—	128
4TS	1/28/43	624	240	10	27	—	0.8	165
4PS	1/28/43	606	258	5	22	—	.1	111
5T	6/1/42	465	136	5	36	.0	—	112
6PD	1/28/43	1,307	230	9	28	—	.0	171
7T	6/7/42	1,274	238	8	30	.0	—	207
7PD	1/28/43	1,279	234	10	28	—	.0	171

of hardness is probably related to the local concentrations of lime nodules found directly above the water sands at different localities. All of the water is low in chloride and in total dissolved solids. Objectionable amounts of iron are present in the water from a few wells.

The water from the "A" sand zone, which is developed in wells 8 and 9 at Camp Polk, has a hardness ranging from 37 to 93 parts per million. A sample from well 9 disclosed only 0.04 part per million of iron. The temperature of this water is about 72°F.

TABLE III

CHEMICAL ANALYSES OF WATER SAMPLES FROM WELLS AT CAMP POLK AND NORTH CAMP POLK
Analyzed by M. D. Foster, L. W. Miller, W. L. Lamar, and E. W. Lohr (Parts per million)

Well number	5	9	11	2PS	2PD	4TS	8T
Depth (feet)	907	689	888	617	1,233	624	1,450
Date of collection	1/28/43	11/24/41	11/24/41	1/28/43	1/28/43	5/17/42	6/17/42
Silica (SiO_2)	74	24	80	46	46	48	54
Iron (Fe)	.02	.04	2.2	.01	1.4	.53	.07
Calcium (Ca)	13	13	16	63	61	59	7.8
Magnesium (Mg)	1.5	1.1	1.3	3.1	3.8	4.0	.6
Sodium (Na)	35	82	30	33	34	35	65
Potassium (K)	2.4	2.7	2.6	4.0	3.8	3.9	2.8
Bicarbonate (HCO_3)	112	235	98	249	260	254	142
Sulphate (SO_4)	7.2	5.3	7.4	11	7.1	5.5	24
Chloride (Cl)	16	15	20	24	19	19	21
Fluoride (F)	.0	.3	.5	.0	.0	.1	.1
Nitrate (NO_3)	.0	.0	.0	.6	.0	.0	.0
Dissolved solids	203	260	201	306	303	300	250
Hardness as $CaCO_3$	39	37	45	170	168	164	22

The hardness of the water from the "B" sand zone differs considerably at the two camps. It ranges from 36 to 51 parts per million at Camp Polk and from 111 to 171 parts per million at North Camp Polk. This difference may be due to the presence of lime nodules directly above the "B" sand zone at the north camp. The iron in the water ranges from 0.01 part per million in well 2PS to 2.2 parts per million in well 11. The occurrence of iron in the water is very irregular and has been reported by W. H. Bates, sanitary engineer, to change from time to time. The temperatures of water from this sand are about 78°F. at the south camp and 72°F. at the north camp, where the sand is nearer the surface.

The water from the "C" sand zone, which has been developed in three wells at North Camp Polk, is moderately hard, ranging from 168 to 207 parts per million. The iron in a sample from well 2PD was found to be 1.4 parts per million. The temperature of water from this sand is about 82°F.

The "D" sand zone supplies the only soft water in North Camp Polk (well 8PD). It has not been developed at Camp Polk. The hardness and iron in a sample from well 8T were 22 and 0.07 parts per million, respectively. The temperature of this water is about 84°F.

PLEISTOCENE AND RECENT SERIES

Distribution and lithology.—About 3 miles south of Camp Polk the Miocene formations are blanketed with unconsolidated materials of the Pleistocene and Recent series. These sediments, extending southward as a continuous sheet of sand, gravel, and clay, thicken from a few feet in the vicinity of Camp Polk to about 290 feet at DeRidder and to several thousand feet on the coast. In Camp Polk and North Camp Polk the Pleistocene and Recent materials have been almost completely eroded from the hills, leaving a few irregular patches of sand and gravel of little extent. The valleys of Bundick Creek, Bayou Zourie, and Castor Creek have been partially filled with this Pleistocene and Recent alluvium.

Water sands.—Although the sands and gravels of the Pleistocene and Recent series are not thick or extensive enough to be considered as a source of water in the cantonments, they do supply numerous farms in the valleys on the north and practically all towns and industries on the south. Relatively large supplies of water may be developed south of the Vernon Parish line. The public supply at DeRidder about 20 miles south of Camp Polk is obtained from wells about 290 feet deep, which are screened in coarse sand and gravel of Pleistocene age. The wells at the DeRidder air base also draw upon this source. The water in this vicinity is soft and has a low total of dissolved solids.

WATER SUPPLIES

CONSTRUCTION OF WELLS

Camp Polk.—The construction of water wells for this cantonment was begun in January, 1941, and completed in June, 1941. Three test holes, one temporary

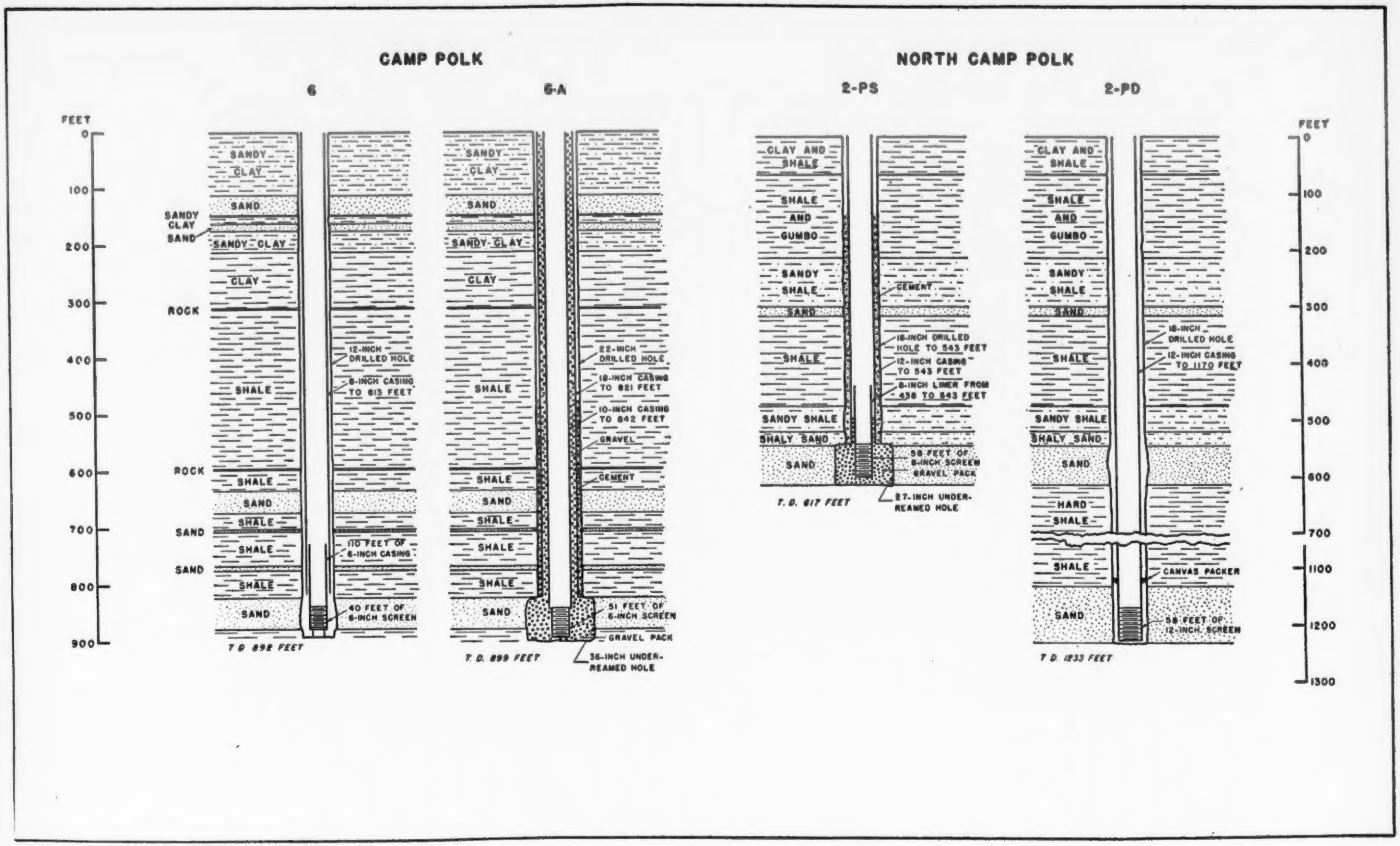


FIG. 7.—Methods of well construction.

well, and nine permanent supply wells, ranging from 678 to 930 feet in depth and from $4\frac{1}{2}$ to 18 inches in diameter, were drilled by hydraulic rotary methods. Electric surveys were made in wells 1, 3, 4, 6, and 8. The records for these 13 wells are shown in Table I.

The permanent supply wells (wells 5, 6, 6A, 7, 8, 8A, 9, 11, and 12) at this camp consist of seven gravel-wall wells that were underreamed from 18 inches to 36 inches in diameter in the water sand, and two wells that are 8 inches in diameter with no gravel wall (see Table I and Fig. 7 for methods of construction). The two 8-inch wells (wells 6 and 8) were drilled as reserve wells to be used for emergency purposes only. The permanent supply wells are located in two lines at right angles to each other, in the shape of an "L." The east-west line of wells is located along the strike of the geological formations; the north-south line of wells follows the regional dip of the beds. The distances between the regular supply wells range from 1,600 to 2,500 feet.

Wells 8 and 9 are screened in the "A" sand at a depth of about 600 feet. The remainder of the wells are screened in the "B" sand at a depth of about 900 feet. The lengths of screen in the wells range from 35 feet in well 8 to 60 feet in well 5. The rates at which the wells were pumped upon completion ranged from 215 gallons a minute (well 8) to 450 gallons a minute (well 6A), with reported specific capacities of 2.4 to 10.5 (Table I). Specific capacities measured in March, 1943, in connection with pumping tests ranged from 3.4 to 15.0. This difference may be accounted for to a large extent by the fact that all wells were tested simultaneously in the original completion tests, whereas they were tested singly in March, 1943.

North Camp Polk.—The expansion of Camp Polk was accomplished in the latter half of 1942 by the construction of a new cantonment, called "North Camp Polk," about 3 miles northeast of Camp Polk. During the preliminary testing for the water supply previous to the drilling of the permanent supply wells, it was suggested that the fresh-water sands known to be present at Leesville[7] to a depth of about 1,200 feet (Fig. 2) be tested by drilling a small-diameter test hole to a depth of 1,600 feet and electrically surveying the formations penetrated in order to evaluate all of the ground-water possibilities. This resulted in the drilling of test well 7T, proving the existence of a good water sand at a depth of 1,171–1,270 feet—the "C" sand zone. A second deep test, well 8T, disclosed a still deeper water sand at a depth of 1,407 to 1,450 feet—the "D" sand zone. Eight permanent supply wells, 12 inches in diameter and 600 to 1,456 feet in depth, were then drilled.

Wells 2PS, 4PS, 6PS, 8PS, and 4TS (temporary) were finished with 50 to 66 feet of screen set in the "B" sand zone (Fig. 5 and Table I) at depths of about 600 feet. These wells, with the exception of well 4TS, are gravel-packed wells underreamed from 18 inches to 27 inches in diameter in the water sand. The rates at

[7] G. C. Matson and E. W. Berry, "The Catahoula Sandstone and Its Flora," *U. S. Geol. Survey Prof. Paper 98-M* (1916), p. 24.

which these wells are pumped range from 215 gallons a minute (well 8PS) to 322 gallons a minute (well 4TS), and the wells have specific capacities of 3 to 15.6 after pumping continuously for one day.

Wells 2PD, 6PD, 7PD, and 8PD were completed with 58 to 86 feet of screen in the "C" sand zone about 1,200 feet deep. None of these wells was underreamed and gravel-packed. Wells 2PS, 6PD, and 7PD are pumped at rates of 245 to 434 gallons a minute, and have specific capacities of 3 to 19 after pumping continuously for one day. Well 8PD continued to yield sand after completion, owing perhaps to improper screening and development, and was finally drilled deeper. An 8-inch screen and liner were set inside the 12-inch casing, and the well was completed in the "D" sand zone at a depth of 1,456 feet. This well is now pumped at a rate of 308 gallons a minute and has a specific capacity of 3.7. This performance, however, can not be considered a good criterion of the potential uspply from this sand. Pumping tests show that the "D" sand has a high coefficient of transmissibility, and mechanical analyses of samples indicate that the sand is very coarse and uniform in grain size.

PUMPAGE AND WATER LEVELS

Pumping at Camp Polk was begun in February, 1941, and that at North Camp Polk was begun in June 1942. For security reasons it is not possible to give exact figures for pumpage, but it can be stated that the combined pumpage at the two camps is several million gallons a day. The bulk of the water pumped at Camp Polk is from the "B" sand. At North Camp Polk most of the water is pumped from the "B" and "C" sands, but since April, 1943, a part of the water has been pumped from the "D" sand.

The reported original static water level of each well at the camps is given in Table I. The water levels in wells screened in the "A" and "B" sands at Camp Polk declined about 20 feet between July, 1941, and May, 1943. The water levels in wells screened in the "B" sand at North Camp Polk declined about 7 feet between January and May, 1943. Owing to the short periods of pumping from the "C" and "D" sands, no appreciable declines of water levels in wells screened in these sands were recorded to May, 1943.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 8 (AUGUST, 1945), PP. 1189-1194, 1 FIG.

TIME OF OIL AND GAS ACCUMULATION[1]

A. I. LEVORSEN[2]
Stanford University, California

ABSTRACT

Oil and gas can not accumulate into pools until a trap has been formed in the potential reservoir rock and the capacity of the trap to hold gas increases as the pressure continues to increase due to deeper burial. The laws of Boyle and Charles, when applied to the Oklahoma City field in Oklahoma, a field typical in its geologic history of many others in the Mid-Continent region, indicates that while the accumulation may have commenced shortly after the sealing of the pre-Pennsylvanian structure by the Cherokee shales, it could not have been completed until the area had been buried to almost its present depth with the consequent increase in pressure. These principles apply to many situations and give a better understanding of the life history of not only oil and gas pools but basins and provinces as well.

Two related principles which aid in considering the time oil and gas accumulate into pools are: first, the practically axiomatic statement that an oil and gas deposit cannot accumulate before a trap capable of holding it in the reservoir rock has been formed, and second, that the capacity of the trap to hold gas is in part a function of the pressure, which in turn is generally related to the depth of burial. These lead to the conclusion that the accumulation may begin at the time the trap was formed and may continue as the increasing capacity of the trap permits.

The date of the formation of the trap in the potential reservoir rock is one of the most significant in petroleum geology, for, while an accumulation may have started in the trap at any time subsequent to its formation, there could be no local accumulation prior to that time. The date the trap was formed, therefore, offers a starting point in the geologic history of an oil and gas pool in considering the time the accumulation took place. Those traps which are stratigraphic—such as sand lenses, shoestring sands, and facies changes,—are coincidental in age with the sealing of the reservoir rock and consequently with the earliest possible date of trap formation. Such traps offer the earliest and longest period of time available for oil and gas to accumulate with respect to the age of the reservoir rock. At a somewhat later date, perhaps, are those traps due to secondary changes in the porosity and permeability of the reservoir rock, such as solution, recrystallization, and channeling. Generally the structural traps form at a still later time in the life of the reservoir rock, some of them closer to the present time than to the time of its origin.

Three examples of later trap formation of the structural type are the following. 1. The reservoir rock of the Kettleman Hills pool in California is the Temblor formation of middle Miocene age and it underlies, without appreciable discordance in dip, the surface formations of Pleistocene age. The time during which accumulation could have taken place must have been after the date of folding and

[1] Manuscript received, June 9, 1945.

[2] Department of Geology, Stanford University.

consequently of relatively short duration compared with the age of the reservoir rock. 2. The Wall Creek sands of the Salt Creek pool of Wyoming are of early Upper Cretaceous age while the folding which formed the trap occurred during the Laramide revolution of early Tertiary time. The accumulation of oil must therefore have been subsequent to the time of folding which was approximately midway in the life of the reservoir rock. 3. Many of the Ordovician sands which produce in Oklahoma were first deformed locally late in Mississippian or early in Pennsylvanian time and suffered repeated minor folding until Permian or later time. The first opportunity for accumulation was subsequent to the late Mississippian-early Pennsylvanian folding, thereby providing a relatively early and long period during which the pool might have developed.

In the foregoing examples and in many of similar type, the first date of the folding can ordinarily be determined with some degree of geologic accuracy. This date in turn becomes the date prior to which there was no appreciable local accumulation of oil and gas since there was no trap at the locality capable of holding the oil and gas. It is upon this principle that the reasoning depends which holds that there has been migration of oil and gas, because, unless the fold-making element in the examples here listed and in similar fields should coincide with the area of origin—an unlikely coincidence—then there must have been a movement of oil and gas into the trap from some outside source area after the trap was formed. In the case of a field such as Kettleman Hills, this time for accumulation was relatively short, whereas in many of the Ordovician and early Paleozoic fields of the Mid-Continent region, the folding which was largely responsible for the trap occurred in late Mississippian or early Pennsylvanian time with a consequently relatively long period of time available for accumulation.

There are some geologists who believe that generally the oil and gas moved into the trap portion of the reservoir rock at an early date with respect to the age of the reservoir rock or to the age of the trap. This may be true in many cases, for it seems reasonable that the older the trap with respect to the age of the reservoir rock the more time it has had in which to trap any oil or gas in the vicinity. However, it does not hold that all oil and gas came in relatively early, and in some fields, at least, there must have been a substantial accumulation continuing long after the date the structure was formed. This reasoning is based on the second principle stated in the first paragraph, that the capacity of the trap to contain gas is a function of the pressure which in turn is roughly a function of the depth of burial or the head of water. In other words, the capacity of a trap to retain gas is a combination of its local structure and character plus the pressure-temperature conditions resulting from the regional geology.

The law of gases—called Boyle's law and Charles' law in physics[3]—is that the volume of a gas varies directly as the absolute temperature and inversely as

[3] $\frac{V^1}{V^2}=\frac{P_2}{P^1}\times\frac{T_1}{T^2}$. Where V represents volume, P absolute pressure, and T absolute temperature.

the absolute pressure. In the case of natural gas there is a deviation from the law when high pressures are encountered and a compressibility factor (CF) is then applied. These laws may be stated as follows.

$$\text{Subsurface volume of a gas} = \text{Surface volume} \times \text{CF} \times \frac{\text{Surface pressure (abs.)}}{\text{Subsurface pressure (abs.)}} \times \frac{\text{Subsurface temperature (abs.)}}{\text{Surface temperature (abs.)}}$$

$$\text{Surface volume of a gas} = \text{Subsurface volume} \times \text{CF} \times \frac{\text{Subsurface pressure (abs.)}}{\text{Surface pressure (abs.)}} \times \frac{\text{Surface temperature (abs.)}}{\text{Subsurface temperature (abs.)}}$$

According to this formula, 1000 cubic feet of gas at conditions of sea-level—60°F. and one atmosphere, 14.7 pounds pressure per square inch—would occupy 5.0 cubic feet of space if buried to a depth where the temperature increased to 132°F., the pressure increased to 2630 pounds per square inch, absolute, and where there was a compressibility factor or deviation from Boyle's law of 27 per cent. This is arrived at as follows.

$$\begin{aligned}\text{Subsurface volume} &= 1000 \text{ cu. ft.} \times \frac{1}{1.27} \times \frac{14.7}{2630} \times \frac{132+460}{60+460}\\ &= \frac{8,702,400}{1,736,852} \text{ cu. ft.}\\ &= 5.0 \text{ cu. ft.}\end{aligned}$$

Likewise, 1000 cubic feet of gas, under conditions existing at 6200 feet below the surface, where the temperature is 132°F. and the pressure is 2630 pounds per square inch, with a compressibility factor of 27 per cent, would expand to occupy 199,510 cubic feet of space if brought to surface conditions of 60°F. and 14.7 pounds atmospheric pressure.

This is arrived at as follows.

$$\begin{aligned}\text{Surface volume of gas} &= 1000 \text{ cu. ft.} \times 1.27 \times \frac{2630}{14.7} \times \frac{60+460}{132+460}\\ &= \frac{1,726,852,000}{8702.4}\\ &= 199,510 \text{ cu. ft.}\end{aligned}$$

The temperature, pressure, and compressibility factor used in the foregoing examples are those which prevailed in the reservoir of the Oklahoma City field, Oklahoma, as shown in Table I.[4] The Oklahoma City field is selected as a test example because it is a large accumulation of oil in a trap whose geologic history

[4] H. B. Hill, E. L. Rawlins, and C. R. Bopp, "Engineering Report on Oklahoma City Field, Oklahoma," *U. S. Bureau of Mines Rept. Investig. 3330*, (January, 1937), p. 218.

is definitely known and is also typical of a large group of oil and gas fields in the Mid-Continent region.[5]

The cross section (Fig. 1) shows the main events in its trap making history to have been a faulted and eroded anticline overlain unconformably by rocks of late Cherokee age (Pennsylvanian). This was followed by the deposition over the area of 6200 feet of Pennsylvanian and Permian sediments, plus an additional unknown amount which has since been eroded, all of which were intermittently folded over the now buried anticline. The evidence for the repeated folding is that

TABLE I

CONDITIONS WHICH PREVAILED AT OKLAHOMA CITY FIELD, OKLAHOMA

	Lower Simpson and "Wilcox" Zones
Initial reservoir pressure, pounds per square inch, absolute	2,630
Initial reservoir temperatures, degrees Fahrenheit	132
Gas in solution at reservoir pressure and temperature, cubic feet per barrel	795
Average gas-oil ratio for oil produced	2000 to 9000
Deviation of natural gas from Boyle's law at reservoir pressure, per cent	27

the intensity of the folding increases intermittently with depth from 90 feet of structural closure at the surface to 250 feet of closure in the Pawhuska limestone at 3200 feet, to 350 feet of closure in the Checkerboard limestone at 5200 feet, and to 600 feet on the Cherokee shales at 6200 feet. Below the unconformity, the structural relief on the reservoir rocks of Ordovician age is at present in the order of 2600 feet, of which 600 feet came in post-Cherokee time and 2000 feet was the result of earlier folding and faulting. When the Simpson sands were tapped in 1929 the trap in the reservoir rock was nearly full of free gas and oil because oil has been found relatively close to the bottom of the bounding synclines at the north and south ends of the anticline.

Geologists often debate as to when the oil and gas entered the trap at Oklahoma City. There is evidence of pre-unconformity accumulation in the large amount of asphaltic material blown from sands. However, from the foregoing reasoning, it seems impossible for more than a minute fraction of the amount of gas found in the field when it was discovered to have been present at the time of burial by the Cherokee shales. The free gas found in the structure, as well as the gas dissolved in the oil, would both require on the order of 200 times as much container capacity to be held at sea level conditions as was required at a burial of 6200 feet. To this increased capacity necessary to hold the gas found in the fold must be added the 600 feet of additional closure which came after Cherokee burial or, in other words, there was three fourths as much closure in pre-Cherokee time as compared with the present closure in the reservoir rock.

[5] A. Travis, "Oil and Gas in Oklahoma—Oklahoma City," *Oklahoma Geol. Survey Bull. 40-SS* (May, 1930).
Homer Charles, "Oklahoma City Oil Field, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 14 (1930), pp. 1515–33.
D. A. McGee and W. W. Clawson, Jr., "Geology and Development of Oklahoma City Field, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 16, (1932), pp. 957–1020.
H. B. Hill *et al.*, *op. cit.*

Two explanations seem possible. The first is that the oil entered the trap early in its history. This might be shortly after burial by the Cherokee shales, as advocated by some, or, as suggested by Dorsey,[6] the oil accumulated in pre-Cherokee time and remained in the structure through the erosion and development of the unconformity by a combination of exceptional circumstances. However, since there was insufficient capacity in Cherokee time to hold more than a fraction of the gas later found in the structure, the gas must have come in later, either from

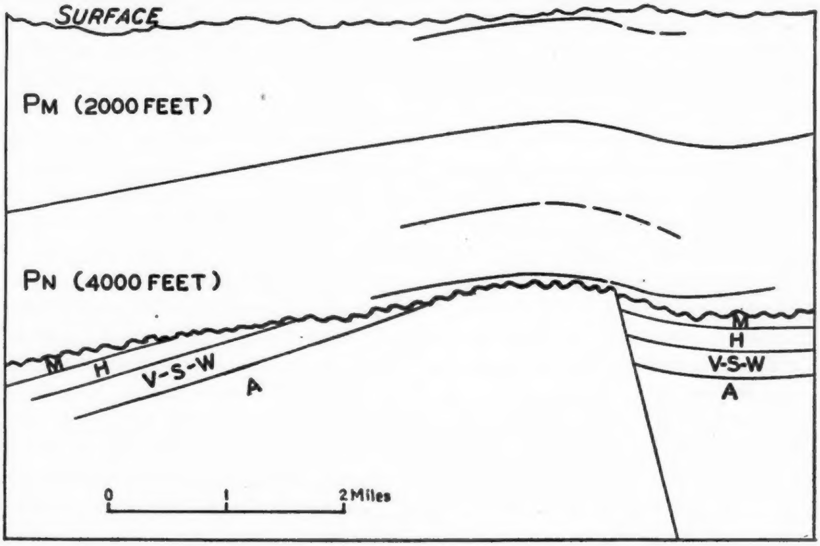


FIG. 1. Idealized cross section of Oklahoma City field, Oklahoma. Symbols used are: *Pm* for Permian; *Pn* for Pennsylvanian; *M* for Mississippian; *H* for Hunton limestone; *V* for Viola limestone; *W* for "Wilcox" sand; *S* for Simpson formation; and *A* for Arbuckle limestone.

an outside source or distilled off the early oil as the pressures increased with burial.

The second explanation is that the gas moved into the trap at some later time and only as the capacity of the trap was increased due to increased reservoir pressures resulting from deeper burial. If such were the case, presumably the oil in some manner came along with the gas. This process might have continued until relatively recent geologic time, since the westward tilting of much of the Mid-Continent region, which resulted in the increased pressures, began in Pennsylvanian time and culminated in the post-Jurassic and pre-Cretaceous interval.[7]

[6] George E. Dorsey, "Preservation of Oil During Erosion of Reservoir Rocks," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17 (1933), pp. 827–42; Discussion, pp. 1271–77.

[7] A. I. Levorsen, "Studies in Paleogeology," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 17 (1933), pp. 1112 and 1121.

By the time the Cretaceous rocks were deposited across the eroded edges of the earlier rocks in the Mid-Continent, the Ordovician sands of the Anadarko basin had sunk to depths ranging from 15,000, to more than 20,000 feet below sea-level while in the bordering regions of the Ozark Mountains, the Wichita Mountains and the Arbuckle Mountains, these sands were being eroded high above sea-level. These geologic movements must have resulted in great changes in the pressures exerted on the contained fluids and gases. The gases either expanded or contracted with the changing pressures and the fluids moved as new outlets were exposed by erosion. Many opportunities were provided, as a result of these disturbances of the equilibrium, for the effects of the differing specific gravities of oil, gas and water to become operative in the segregation of oil and gas pools in local traps.

The second explanation seems the more reasonable of the two since it provides a trap capacity sufficient to contain the gas which was present when the reservoir was tapped in 1929 and at the same time provides the geologic setting which disturbed the equilibrium of the reservoir gases and fluids and thereby caused widespread movement and readjustment to the new conditions.

These two principles, which are in effect interdependent, may be applied to the problem of the time of accumulation in many oil pools as well as to other problems concerned with an understanding of the life history of an oil field. And, if they apply to individual oil fields, they should also apply to larger units, to regions and to provinces. For example, they have a bearing on our understanding of the factors fundamental to the development of an oil province; on the nature of the forces which come into play when the fluid equilibrium is upset by erosion, diastrophism, and pressure changes; on the cause of under-saturated oil pools; and on many of the speculative theories and ideas behind decisions to explore or not to explore new regions. Geologists can not know too much about the sequence of events which culminate in the formation of an oil and gas field, and these ideas are submitted as an approach which may be helpful.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 8 (AUGUST, 1945), PP. 1195-1202, 2 FIGS.

GEOLOGICAL NOTES

TEXTURAL STANDARD FOR SAMPLE LOG WORK[1]

GORDON RITTENHOUSE[2]
Morgantown, West Virginia

When examining well cuttings, it is difficult to be consistent from day to day in describing texture. Also, the work of different men may not be comparable. To eliminate these difficulties, a textural standard has been developed and is used for sample log work by an increasing number of geologists in the Appalachian basin.

The standard, illustrated in Figure 1, is convenient, durable, and easy to prepare. It consists of medium sand, fine sand, very fine sand, and coarse silt mounted loose in the four cavities of a 3×1-inch micropaleontological slide. This slide and a covering 3×1-inch glass slide are held firmly together by an aluminum holder.

The medium, fine, and very fine sand are sieve separates of the 0.500–0.250 mm., the 0.250–0.125 mm., and the 0.125-0.062 mm. size grades of Tyler standard sieves. Thus they conform to recommendations of the Committee on Sedimentation of the National Research Council. The coarse silt is sediment passed by the 0.062 mm. sieve, from which material finer than about 0.01 mm. has been removed by repeated decantation. The standard for each size class is obtained from sediment in which the modal size approximates that of the size class.

A drop of water placed in each cavity prior to mounting will swell the edges of the adjacent paper, thus forming a tight seal against the cover and preventing the silt and fine sand from "traveling."

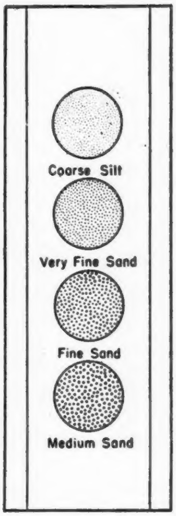


FIG. 1.—Textural standard.

[1] Manuscript received, May 12, 1945. Published by permission of the director of the Geological Survey, United States Department of the Interior.

[2] Geological Survey.

DEEP OIL TEST AT SALISBURY, WICOMICO COUNTY, MARYLAND[1]

HORACE G. RICHARDS[2]
Philadelphia, Pennsylvania

The first serious test for oil in the middle Atlantic Coastal Plain was the well drilled by the Ohio Oil Company on the L. G. Hammond farm, 6 miles east of Salisbury, Wicomico County, Maryland, on the Mt. Hermon road (elevation, about 57 feet). Drilling was started on October 12, 1944, and completed at the

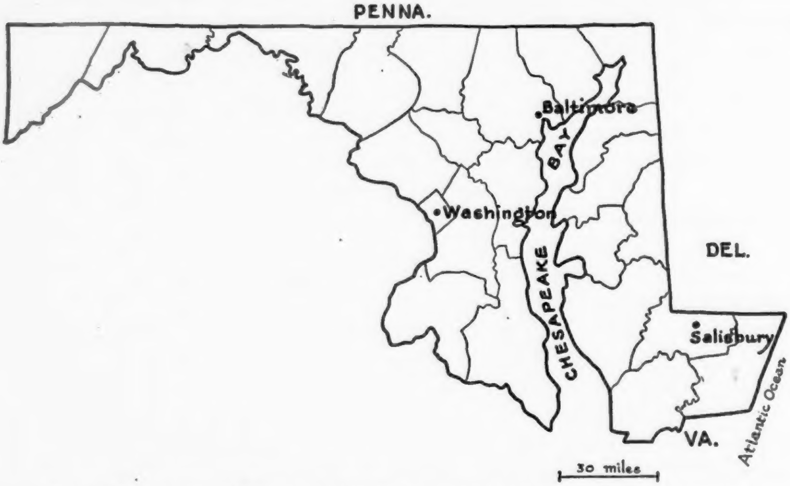


FIG. 1—Sketch map of Maryland, showing location of Salisbury, Wicomico County.

depth of 5,568 feet on January 12, 1945. The well was drilled by rotary methods and was cored from the depth of 1,000 feet to the bottom. No traces of oil were found.

Brief mention has already been made of this well[3] and it is probable that a more complete report will be prepared by the Maryland Geological Survey. However, in view of the importance of this well, the deepest hole of its kind in the region, a brief discussion of the log and correlation is presented herewith.

The writer had the opportunity of examining the samples during the course of the drilling, and is indebted to Stanley B. White, of the Ohio Oil Company, for

[1] Manuscript received, June 18, 1945. This paper is part of a study of fossils from wells and outcrops of the Atlantic Coastal Plain, supported by grants from the Penrose Fund of the Geological Society of America and the Johnson Fund of the American Philosophical Society.

[2] Associate curator of geology and paleontology, Academy of Natural Sciences.

[3] Horace G. Richards, "Subsurface Stratigraphy of Atlantic Coastal Plain between New Jersey and Georgia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 7 (July, 1945), p. 903.

permission to use the information at this time. Meredith E. Johnson, State geologist of New Jersey, spent two days examining the cores with the writer and gave the benefit of his correlations with the New Jersey section. Ruth Patrick, associate curator of microscopy at the Academy of Natural Sciences of Philadelphia, prepared the note on the Miocene diatoms which is included herewith. H. N. Coryell, of Columbia University, New York, and several other petroleum micropaleontologists identified the microfossils in certain of the samples. Judith Weiss, of Bryn Mawr College, supplied the petrographic description of the basement rock quoted herewith. The following log and correlations are based on the writer's study of the lithologic character and the macrofossils of the cores and cuttings, and examination of the electric log, together with information supplied by various persons. The correlations, however, are those of the present writer, and do not necessarily reflect the views of the individuals quoted.

Depth in Feet	*Time Division*	*Formation*

0–100 PLEISTOCENE Wicomico
Sand and gravel, some iron-stained; no fossils.

100–320 MIOCENE Cohansey
Sand and gravel, a little clay; probably some gravel washed down from above. Lignite at 300 feet.

The sediments resemble those assigned to the Cohansey in wells at Bridgeville, Delaware, and Brandywine Lighthouse, New Jersey, except that the gravel is more conspicuous. The Cohansey formation is regarded as the non-marine equivalent of the Yorktown.

320–540 MIOCENE St. Mary's
Sand, small gravel, and shells. Among typical mollusks are: *Turritella variabilis* Conrad, *T. plebia* Say, *Nassarius peralta* (Conrad) *Polinices duplicata* (Say), *P. heros* (Say), *Melampus quadratus* (Conrad), *Crepidula fornicata* (L.), *Terebra simplex* Conrad, *T. curvilirata* Conrad, *Drillia limatula* (Conrad), *Nucula proxima* Say, *Mulinia lateralis* (Say), *Cardium laqueatum* Conrad, *C. patuxentium* Glenn, *Leda acuta* Conrad, *Dentalium caduloide* Dall, *D. attenuatum* Say.

In many wells it is impossible to separate the Yorktown, St. Mary's, Choptank, and Calvert formations, all of which constitute the Chesapeake group.

540–620 MIOCENE Choptank
Sand, sandstone and shells; slightly more consolidated than the St. Mary's. Mollusks mostly fragmentary, but following species are identified: *Pecten madisonius* Say, *Phacoides crenulatus* (Conrad), *Ostrea sellaeformis* Conrad, and *Balanus* sp.

The Choptank probably represents a late, sandy phase of the Calvert.

620–1160 MIOCENE Calvert
Sand and shells (650–710 feet); clay and shells (710–1160 feet). Many typical Calvert mollusks, including: *Calyptraea aperta* (Solander), *Pecten madisonius* Say, *Chama congregata* Conrad, *Melina maxillata* (Deshayes), *Antigona staminea* (Conrad), and *Cadulus thallus* Conrad.

Marine diatoms were present between 800 and 1,150 feet, and probably represent the "Great Diatom bed" of the Kirkwood formation of New Jersey. Ruth Patrick has written the following statement on the diatom flora.

The material from 800 to 1150 feet contained diatoms which typically belong to the

Miocene period. The lowest true diatom flora existed at 1130–1140, there being just a few frustules at the 1140–1150 level. The 1130–1140-foot level was examined critically as it represented the oldest diatom flora. The following species were identified: *Actinocyclus crassus* (W. Smith) Van Heurck, *A. Ehrenbergii* Ralfs, *A. Heliopelta* var. *versicolor* Brun, *Actinoptychus undulatus* (Kutzing) Ralfs, *Cossinodiscus lineatus* Ehrenberg, *C. perforatus* Ehrenberg, *Diploneis Szontaghii* Pantock, *Melosira sulcata* (Ehrenberg), *Rhaponeis gemmifera* Ehrenberg.

It is interesting to note that the typical *Actinoptychus Heliopelta* with the star-shaped central area is absent from this deposit. This diatom is characteristic of the oldest part of the Miocene on the Eastern Coast. This fact may indicate that the lowest part of the Miocene is absent in this series. However, most of the species indicated have been found in the Calvert formation.

Apparently the "Lesser Diatom bed" of the Kirkwood, which is present in wells between Atlantic City, New Jersey, and Lewes, Delaware, is absent at Salisbury.

Some characteristic upper or middle Miocene Foraminifera identified between 1140 and 1150 feet, the only Miocene sample examined for microfossils: *Buliminella curta* Cushman, *B. gracilis* Cushman, *B. marginata* var. *multicostata* Cushman, *Cassidulinoides bradyi* Cushman, *Cibicides concentricus* Cushman, *Lenticulina rotulata* Lamarck, *Discorbis subaraucana* Cushman, *Globigerina bulloides* (d'Orbigny), *Guttulina irregularis* d'Orbigny, *Uvigerina* sp. *Virgulina fusiformis* Cushman.

1160–1200 EOCENE Jackson (?)

Greenish clay; some glauconite; Foraminifera. Coryell recognized some "late Eocene" species in sample at 1170–1180 feet, including: *Cibicides lobatulus* Walker and Jacob, *Dentalina jacksonensis* (Cushman and Applin) *D.* cf. *vertebralis* (Batsch), *Globulina inaequalis* Reuss, *Gyroidina guayabalensis* Cole, *G. orbicularis planata* Cushman, *Mississippina* sp., *Robulus* cf. *alato-limbatus* (Gumbel) *Siphonina advena eocenica* Cushman and Applin, *Textularia hockleyensis* Cushman and Applin.

The presence of some characteristic Jackson species suggests the presence of a thin section of late Eocene age. On the other hand, fragments of *Pecten delawarensis* and *Solidobalanus* found in the Bridgeville or Brandywine Lighthouse wells, were not noted.

1200–1380 EOCENE Lower Pamunkey and Midway?

Glauconitic clay, some sand, shell fragments, and Foraminifera. Macrofossils fragmentary and difficult to determine, although following are recognized: *Ostrea compressirostra* Conrad, *Corbula* sp., *Pecten* sp.

Early Eocene or Paleocene Foraminifera in samples between 1210–1220, and 1240–1250 feet, including: *Astacolus* cf. *crepidulus* (Fichtel and Moll), *Bulimina* cf. *arkadelphiana* var. *midwayensis* Cush. and Parker, *B. cacumenata* C & P., *Cibicides alleni* (Plummer), *Epistomina* cf. *eocenica* Cushman and Hanna, *Globigerina triloculinoides* Plummer, *G. pseudobulloides* Plummer, *Globorotalia crassata* (Cushman) var., *G. wilcoxensis* Cushman and Ponton, var. *acuta* Toumlin, *Gumbelina* cf. *wilcoxensis* Cushman and Ponton, *Gyrodina aequilateralis* (Plummer), *G. plummerae* Cushman and Bermudez, *G. subangulata* (Plummer), *Nodosaria affinis* d'Orbigny *Pullenia quinqueloba* Reuss var., *Allomorphina* cf. *halli* Jennings, *Robulus turbinatus* (Plummer).

The Claiborne and upper Wilcox equivalents are very thin or absent, and it is probable that the Eocene in this well represents the lower part of the Aquia which is equivalent to the Hornerstown formation of New Jersey. The absence of typical Vincentown limesand with bryozoans and serpulids is noteworthy. It is believed that the lower part of the subsurface Hornerstown (and Aquia) dates from the Midway, which may explain the presence of the Paleocene Foraminifera.

The relatively thin Eocene section (230 feet) in this well is in contrast to that

immediately north of the James River, as reported by Cederstrom[4] where it attained a thickness of 830 feet at Fort Monroe, Virginia.

1380–1807 UPPER CRETACEOUS Monmouth-Matawan
Gray and green sandy clay, some glauconite and lignite. Characteristic late Upper Cretaceous Foraminifera equivalent to Navarro and Taylor formations recognized at 1380–1390, 1433–1440, and 1588–1598 feet, including: *Bolivinoides decorata* (Jones) var., *Cibicides* cf. *harperi* (Sandidge), *Gaudryina* cf. *rugosa*, *Globigerina cretacea* d'Orbigny, *Globigerinella voluta* White, *Globotruncana cretacea* Cushman, *Gumbelina globulosa* (Ehrenberg), *G striata* (Ehrenberg), *Gyroidina depressa* (Alth), *G. alabamensis* Sandidge, *Loxostoma plaitum* (Corsey), *Pseudouvigerina plummerae* Cushman, *Robulus navarroensis* (Plummer), *Bulimina elongata* d'Orbigny, *Bulinonella fusiformis* Jennings, *Dentalina basitorta* Cushman, *D. communis* (d'Orbigny), *D.* cf. *vertebralis* (Batsch), *Guttulina hantkeni* Cushman and Ozawa, *Lenticulina degolyeri* Plummer, *Siphonia prima* Plummer.
Between 1568 and 1618 feet a layer of olive-drab sandy clay contains many shell fragments. Most are unidentifiable, although the following are recognized: *Mytilys salisburyensis* Richards, *Corbicula wicomicoensis* Richards, *Corbula whitei* Richards, *Corbula* sp.

Microfossils are not very abundant in this zone, although a few are present in the 1,588–1,598-foot sample.

1807–1924± UPPER CRETACEOUS Magothy
Varicolored clay, some sand, lignitic and micaceous. This grades downward imperceptibly into Raritan.

1924±–2267± UPPER CRETACEOUS Raritan
Varicolored clay, some gray sand. Much lignite; shell fragments, 2240–2277 feet (*Nucula*? sp., *Panope* sp., *Corbula* sp.). No microfossils except *Inoceramus* prisms and echinoid spines at 2257–2267 feet.

This zone may represent the marine phase as exposed at Sayreville, New Jersey, and in wells at Fort Dix, New Jersey, and Clementon, New Jersey. It is probably equivalent to the Tuscaloosa formation of the Gulf Coast. The Cretaceous section below 1,618 feet is predominantly non-marine.

2267±–2375 LOWER CRETACEOUS Potomac group; Patapsco formation
Greenish drab and red-brown clay; some sand and lignite.

This formation is difficult to separate from the above and it is probably conformable. It is approximately equivalent in lithologic character and thickness to the outcropping Patapsco formation of Maryland.

2375–2560 LOWER CRETACEOUS Potomac group; Arundel formation
Mottled red and green clay.

This formation is similar in lithologic character and thickness to the outcropping Arundel in Maryland. The base of the Arundel and the transition from clay to sand is clearly shown in the electric log.

2560–2925 LOWER CRETACEOUS Potomac group; Patuxent formation
Mixture of sand and clay; much more sandy than above; color varies between red, gray, and green; lignite. Shell fragments and Foraminifera were found between 2749 and 2759 feet, but the species are definitely post-Cretaceous, and probably represent contamination.

2925—5360 LOWER CRETACEOUS Undifferentiated
Alternating layers of sand and clay, generally more consolidated near bottom. Much lignite. Particularly consolidated layers of sandstone noted at 3804–3804½; 4051–4053; 4237–4239; 4111–4143; 4582–4592; 4632–4637; 4798–4818 feet. Some sandstone calcareous. Pebbles here

[4] D. J. Cederstrom, "Structural Geology of Southeastern Virginia," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 29, No. 1 (January, 1945), pp. 71–95.

and there. At 4963½, shell fragments including ***Belemnitella***, but probably fallen from above. Ditch samples, taken when core recovery was not satisfactory, contain fragments of Miocene fossils, indicating contamination.

Below 5,000 feet, most of the clay has been altered by pressure into siltstone or claystone, but none is as consolidated as the Triassic shale. The entire section is predominantly, if not entirely, non-marine, and may indicate deposition in an ancient delta, the ancestor of the Potomac or Susquehanna rivers and Chesapeake Bay.

It is possible that this section represents the seaward thickening of the Potomac group. However, inasmuch as the three divisions of this group can be recognized, it is more probable that these underlying sediments are older than the Potomac, possibly early Lower Cretaceous in age, or even Jurassic, and do not crop out. Deposition may well have been continuous in a large estuary from early Lower Cretaceous (or Jurassic) through the Magothy formation, thus accounting for a thickness of 3,553 feet of predominantly non-marine sediments. It is hoped that further wells in this area will shed more light on this subsurface material. Possibly plant fossils will be found which will establish the age of the material. It is highly probable that a new formation name will have to be used for these alternating layers of sand and clay below the Potomac. At no place, either in outcrop or in wells, do true Potomac sediments become as consolidated as those in the deeper parts of the Salisbury well.

5360–5529 TRIASSIC, Newark
Red and greenish shale, with alternating layers of coarse arkosic sandstone.

This is very similar to outcrops of the Newark series in Pennsylvania and New Jersey. This is the first record of Triassic sediments under the Coastal Plain of Maryland. Deposits of similar age are known to underlie the Cretaceous at Dunhams Corners, New Jersey, and Bowling Green, Virginia, and possibly at Summerville, South Carolina, and Florence, South Carolina. (See Richards, 1945, *op. cit.*)

5529–5568 PRE-CAMBRIAN (?) Basement complex
5529 Medium-grained crystalline rock injected with granite
5536 Fine-grained crystalline rock composed dominantly of ferromagnesium and plagioclase feldspar minerals
5542 Same as 5529 with calcite veins
5542–47 Granite pegmatite
5568 Total depth of well

The age of this basement rock is uncertain, but it is tentatively assigned to the pre-Cambrian. Near the contact with the overlying Triassic it is apparently highly metamorphosed.

The following note on the petrography of this basement rock was prepared by Miss Judith Weiss.

Slide of Well Core 664 (5537–5542 feet)
The hand specimen is a light-colored rock, rather granitic in appearance and shot through with veins of calcite.
Thin section.

Minerals Present	*Approximate Percentage*
Calcite (hydrothermal)	25
Quartz	20
Orthoclase	20
Plagioclase (albite)	10–15
Muscovite	3–5
Sericite	5–8
Myrmekite	5–10
Magnetite	1
Tourmaline	Less than 1

The calcite appears to be hydrothermal. Most of the plagioclase is replaced by myrmekite (vermicular intergrowth of plagioclase and quartz), and much of the muscovite is in the form of scaly masses of sericite.

Slides of Well Core 666 (5542–5547 feet)

I. Upper Specimen

The hand specimen has an appearance much like the Baltimore gneiss of southeastern Pennsylvania and northeastern Maryland. There is a definite alignment of the darker minerals, giving the rock a gneissic structure.

The thin section is much more granitic in appearance than the hand specimen.

Minerals Present	*Approximate Percentage*
Orthoclase	50–55
Quartz	25
Biotite (altering to chlorite and sericite)	5
Plagioclase (albite)	5
Myrmekite	5
Calcite	5–10
Garnet	Less than 1
Sphene	Less than 1

The quartz has wavy extinction and the feldspar is much fractured, indicating mechanical deformation subsequent to the development of the gneissic structure. Hydrothermal calcite is deposited in the fractures in the feldspar. Much of the biotite is greatly altered to chlorite and sericite. Most of the plagioclase appears to be replaced by masses of myrmekite.

II. Middle Specimen

The hand specimen is of a rock which seems to have been much more metamorphosed than the above specimen. The rock is crossed by bands of hydrothermal calcite, and contains much garnet visible to the unaided eye.

Minerals Present	*Approximate Percentage*
Orthoclase	45
Quartz	10
Muscovite	5
Sericite and minor chlorite	2–3
Plagioclase (albite)	1
Myrmekite	2–3
Calcite	15
Hornblende	10–15
Diopside (altering to sericite)	2
Garnet	2–3
Sphene	Less than 1
Magnetite	Less than 1
Tourmaline (Fe)	Less than 1

The veins of hydrothermal calcite have probably combined with some of the silica (in the quartz and the feldspar) of the rock, reducing the per cent of those two minerals, and producing the calcium silicates, diopside, hornblende and garnet.

III. Lower Specimen

Thin section.

This appears to be more granitic in character than the other two specimens from this core, but it contains no mafic minerals. Hydrothermal calcite is still present though in not as great an amount.

Minerals Present	*Approximate Percentage*
Quartz	20–30
Plagioclase (albite)	10
Myrmekite	3–5
Orthoclase	40–50
Calcite	5
Sericite	2–3

The plagioclase is much replaced by myrmekite.

NEW SPECIES OF MOLLUSKS

Fuller descriptions and illustrations will be published in the *Journal of Paleontology*. The following brief summaries are published in order to validate tbe species and to be able to refer to them in the present discussion.

Mytilus? salisburyensis Richards New species

Shell of moderate size, sub-circular; umbones not shown, but apparently central. Finely striated with ribs equidistant from each other. No trace of concentric ribs. Very nacreous.

Dimensions of type: length, 18 mm.; width, 7 mm.

Common but poorly preserved in the core between 1588 and 1598 feet in well 6 miles east of Salisbury, Maryland.

Age: Upper Creatceous (probably Matawan group).

Type: A.N.S.P. 16711.

Corbicula wicomicoensis Richards New species

Shell small, rounded trigonal; beak central; prominent groove on left. Cardinal teeth bifed at summit. Concentric growth lines conspicuous and at irregular distances from each other.

Dimensions of type: length, 5.5 mm.; width, 4.5 mm. (broken).

Not like any species of *Corbicula* from the East Coast Cretaceous, but related to *C. cytheridiformis* Meek and Hayden from the Western Interior.

From core between 1588 and 1598 feet in well 6 miles east of Salisbury, Maryland.

Age: Upper Cretaceous (probably Matawan).

Type: A.N.S P. 16712.

Corbula whitei Richards New species

Left valve with shell smooth, sub-triangular; beak incurved; prominent groove below the beak. Resembles *C. crassiplica* Gabb but with slightly higher beak and more equilateral.

Dimensions of type: length, 4.0 mm.; width, 5.0 mm.

From core between 1588 and 1598 feet in well 6 miles east of Salisbury, Maryland.

Age: Upper Cretaceous (probably Matawan).

Type: A.N.S.P. 16713.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 8 (AUGUST, 1945), PP. 1203-1207

RESEARCH NOTES

OUTLOOK FOR RESEARCH IN EXPLORATION[1]

ROY R. MORSE[2]
Houston, Texas

A few years back an anonymous contributor[3] gave his impressions of research and research men, in part in the following language.

> It is not absolutely necessary to have a research department. . . . In some businesses there isn't really much left to find out. . . . Research is a long-term affair, and in some types of business the long term may only come after the business has come to an end. . . . The greatest of all the research problems is the people who do the research, and in dealing with them Patience is not only a virtue but a necessity. Remember that the research worker's motto is: "Rome was not built in a day. . . . " So the three-hundred-and-sixty-six days of a Leap Year when the research department doesn't discover anything are presumably some of the days when Rome was not built. It is . . . useless to point out . . . that sales are falling, that profit margins are non-existent, and that they haven't turned out a new idea for fifteen years. . . . They are scientists, and you can't hurry science. It was precisely to avoid being worried by this sort of nonsense that they became research workers. . . . Try not to interrupt the research department with petty matters. It is a common mistake . . . to say, "Well, why shouldn't we get the research people in on this?" . . . This shows an entire lack of understanding of the meaning of research . . . for with problems of this kind an answer is usually required quickly—say before the following winter . . . and it is clear that to demand an answer to a question before next winter is very like trying to build Rome. . . .

While this was a humorist's vignette of research some time ago, his analysis promotes a more serious train of thought which to-day we can well afford to pause and consider. War has done some strange things to us: to research, to management. One very important change is the improved general outlook on the research front.

Viewed through prewar glasses, many accomplishments approach the stature of miracles in research, development, and production. The period of the crisis has demonstrated in most convincing fashion what can result from mobilization of men and brains and ideas, concentrating on specific objectives when time is of the essence. This object lesson will not be forgotten by those employing research men nor by the research men themselves. Management in general is more research conscious than ever before, and those engaged in research have seen demonstrated the importance of practicality and the time element. Our peacetime horizons in research have permanently expanded.

To those few who are fully aware of the technical achievements brought about by the war crisis this conclusion is self-evident. To numerous more isolated in-

[1] Manuscript received, June 22, 1945.

[2] Shell Oil Company, Inc.

[3] "On Research," *Punch* (September 18, 1935), p. 316.

dividual research workers who contributed materially to successful results in numerous fields of investigation the changed outlook for the future may not be so obvious; yet it is to this group to which industrial research must look in its recruiting campaign of the next few years. Speaking specifically as to the field of mathematics, one eminent authority[4] closely connected with the progress of research during the war has recently expressed his views on this subject as follows.

> The great depletion of material resources which this country has recently suffered demands a reconsideration of our spendthrift methods. . . . A much wider use of analytical methods than has been employed in the past will be forced upon many businesses by economic necessity. . . . The ever-increasing need for more precise and exacting products and devices entails an ever-increasing need for a high degree of skill on the part of those engaged in research, development and production.

A recent report from the management front[5] supports this prognosis in the following language.

> The National Research Council's Office of Scientific Personnel quietly polled representative laboratories, including most of the top-ranking ones, for a conservative estimate of their plans and needs. All the laboratories, instead of cutting back, hope to enlarge their staffs at war's end. Total planned increase: 20%. The biggest laboratories, convinced of a research boom in postwar business, expect to hire about three times as many scientists as they did before the war.

Recognizing then the desire and intent on the part of management for an expanded and concentrated research program for the future, let us examine a little more closely what this means to us who are engaged in the assignment of exploration for oil reserves. What do we mean by exploration research, and just what should its relations be to any other kind of research?

At the outset it seems clear that our general field falls chiefly in the category of industrial research and development rather than in the realms of academic or "pure" science. The following is quoted from the report of a recent valuable symposium[6] on this subject.

> Increase in the sum of human knowledge . . . is the function of scientific research. . . . The new application of existing knowledge . . . is development. The amount of scientific knowledge already available which . . . has not yet been applied is almost always far greater than the new contributions to human knowledge which any industrial research organization can hope to make . . . therefore, industrial research work is mainly development work. . . . The third component of industrial research is . . . invention. . . . It is the function of industrial research to harness the three components in a sustained common effort and to keep the effort headed in the right direction.

We may elaborate this idea somewhat after the form of a chemical equation as follows:

[4] Richard Stevens Burington (Bureau of Ordnance, Navy Department), "New Frontiers," *Science*, Vol. 101, No. 2622 (March 30, 1945), p. 314.

[5] "Research Boom," *Time* (May 7, 1945), p. 56.

[6] Frank A. Howard, *The Future of Industrial Research*, Standard Oil Development Company (1945), p. 4.

Academic Research (facts and laws)→
Industrial Research (application)→
Development (invention and patents)→
Manufacture and Distribution.

We may, then, narrow the field somewhat by bearing in mind that the new application of existing knowledge (facts and laws), rather than the discovery of new laws governing the universe, is the more profitable field for us. The existing body of known facts and laws is great, it is their application that lags; as witness the vacuum into which *application* and *development* poured during the war crisis when time was measurable in human lives.

Our own field, then, is chiefly that of further and better application of known facts and laws governing oil-finding, and developing or perfecting the necessary tools. Our specific objective is to rebuild our inventory of crude oil reserves *now*, not 15 years hence. In general terms this assignment can be handed to our research men in the form of this simple question: how can we improve our prospect-finding technique?

In handing this assignment to the research men let us take note of the fact that in the past confusion, misplaced emphasis, and sometimes a serious waste of effort has arisen from lack of understanding or appreciation of the factors involved in the general problem of maintaining reserves. This confusion has existed in the ranks of both management and research. When we suddenly found ourselves at war with requirements for petroleum products sky-rocketing it should have been obvious that meeting this demand, with one eye on future security as well, was not merely a matter of opening the gate valves another notch, nor of arbitrarily stimulating leasing and wildcat drilling; it was not simply a question of the availability of steel or manpower, nor was it one that could be directly solved by regulating the price of crude oil. The basic requirement was and still is that of *improving our prospect-finding* technique forthwith. This meant research.

Symptoms of this misplaced emphasis are to-day still in evidence. Opening the gate valves was an expedient which promptly ran headlong into the "m. e. r.," that is, eventual loss of reserves through lowered ultimate recovery. Official sponsorship of an accelerated wildcatting campaign has had the following result, as reported by the American Petroleum Institute.[7]

> 1944 witnessed one of the greatest wildcatting campaigns in oil history, but new fields discovered failed to keep pace with wartime rate of withdrawal.
>
> What the government will do if military oil demands should again be increased is a three-horned dilemma; fields are now producing above their maximum efficient rate, and 27,000 new wells are called for in 1945—production beyond optimum might be necessary, or increased imports, or less civilian consumption.

The stimulation of easy money resulted chiefly in leasing and drilling wildcats against longer odds without improving the reserve position. Anyone can buy

[7] *Amer. Petrol. Inst. Quar.* (April, 1945), supplement.

leases and drill dry holes, but it is increasingly evident that it takes skilled and carefully planned exploration to find prospects on which to drill oil wells. At no time in the course of events of the past few years has the current level of wildcatting or leasing afforded any real index of current prospect-finding abilities.

Within our own ranks we have in the past given evidence of similar confusion and lack of perspective in our research efforts. It has not always been clear just who should do what kind of research toward which objective. With the principles outlined in earlier paragraphs in mind it seems clear that tomorrow's exploration research should fall primarily in the range of *application* of known laws and facts. This does not mean that we should neglect long-range or "fundamental" research in the field of applied science. We have good tools for oil-finding purposes, using well established principles; we could use more, since some of these are, in some areas, now approaching the point where the law of diminishing returns begins to function. We lag considerably in our understanding of the significance of the measurements which our present tools are giving us, and we need to perfect them further, to the point where they may give us better and more complete data.

Moreover, in our urge to be practical we have not yet fully grasped the possibilities of the multiple attack with methods already at hand. We have not always used the scientific approach, the method of "multiple hypotheses" with elimination of the unfit where two independent sets of measurements fail to match. Frequently we are not sufficiently critical of our criteria. Our efforts do not become "academic" merely because we use the eminently practical step called for in what is commonly known as the "scientific method" of approach.

In some areas we obtain reflections from the "top of the Selma" and fail to translate these into terms of underlying structure or stratigraphy; we get reflections from depths greater than 15,000 feet but do not know what they mean nor how to correlate them; we discover gravity "anomalies" which we do not understand, and "halos" of soil hydrocarbons whose origin and significance are in doubt; magnetic and electrical "anomalies" are common, but translating them into structural terms is still a research problem. These and many other problems of like nature would seem to constitute the major field for exploration research in the immediate future; they include ample room for certain long-range but practical studies of fundamentals. They are subjects well suited for real research under private enterprise. Other more general problems dealing with such subjects as the original source material of oil, regional problems in isostasy, the origin and growth of mountain ranges, the strength of the earth's crust, *et cetera* are, like speculations regarding continental drift, intriguing and perhaps of long-range value, but by their very nature are more suitable for public institutions designed and equipped for research in wider fields.

Our total proved reserves at the last year-end were 20.4 billion barrels, against 1.68 billion barrels withdrawn during the year.[8] The ratio indicated is approxi-

[8] *Amer. Petrol. Inst. Quar.* (April, 1945), pp. 36–38.

mately 12, which means that if these reserves were all above ground they would last for just 12 years at this rate of consumption. A very large capital investment is represented by the oil industry in the United States and 12 years is not too long a period to provide for the eventual liquidation of this investment account, irrespective of possible future requirements for national security. With the numerous unsolved and very practical problems before us, exploration research need not go far afield in its activities. It should be stratigraphic rather than stratospheric. If we wander too far from the main objective this next 12-year period will turn out to be another one of those intervals within which "Rome was not built."

Admitting, then, that we have plenty of immediately urgent and specific problems in exploration worthy of the attention of the best research talent available, and that time is of the essence, let us again take note of the fact that management is fully aware of this situation. We are in the unusual position where we not only can but must write our own ticket. Those who are daily confronted with the successes and failures in current prospect-finding technique must write the program. Oil-finding research programs must originate largely in the places where the problems must be solved, not in the minds of some remote General Staff or Higher Board of Strategy.

Here is a real challenge, and how will we in the profession meet it? Some of the necessary items involved in the answer which seem to the writer to be important are the following. We must keep our eyes on the main objective; new reserves now, not some time in the dim future when our whole economy may be changing from one of gasoline to one based on disintegrating the atom. In *all* our work we must be intellectually honest with *all* our facts, using the open-minded "scientific approach" of research. We must analyze our mistakes intelligently—every dry hole tells us something. We must write our own future program of oil-finding; no one else can do it for us successfully; and in doing so we must be specific, and talk the language of management—we can not expect them to talk ours. They are responsible to stockholders, who enjoy reading reports of progress and dividends, but who are leaving it chiefly up to us to work out the details.

It may be well for all of us to remember that research is, after all, not a laboratory, not necessarily a particular group of people in a certain place, but like Heaven chiefly a condition of the mind. Actually the maximum requirement called for may be merely "the use of an unusually intelligent train of thinking leading to a sound conclusion." In a general sense every geologist or geophysical crew entering a new area is engaged in some sort of research; every subsurface study is a research problem; and every wildcat a research experiment. If we are to meet the challenge successfully, all of us who are engaged in any branch of exploration for new reserves must be research-minded, recognizing that it is possible to apply the sound principles and methods of the so-called "scientific approach" without becoming academic.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO 8 (AUGUST, 1945), PP. 1208-1214

REVIEWS AND NEW PUBLICATIONS

* Subjects indicated by asterisk are in the Association library, and are available, for loan, to members and associates.

STRATIGRAPHICAL CLASSIFICATION AND NOMENCLATURE, BY F. R. S. HENSON

REVIEW BY BURTON WALLACE COLLINS[1]
Auckland, New Zealand

Stratigraphical Classification and Nomenclature, by F. R. S. Henson. *Geol. Mag.*, Vol. 81, No. 4 (for July-August, published June, 1944), pp. 166–69.

This short paper contains several interesting suggestions worthy of consideration by those who agree that "greater uniformity of practice could and should be achieved in stratigraphical classification and nomenclature." In the author's own words:

> In order to promote clear thinking, accuracy of expression and uniformity of practice in stratigraphy, it is contended that every formal representation of a sedimentary sequence should give a dual classification—
>
> (a) In terms of classical time-units, according to the author's interpretation, which remains subject to revision.
>
> (b) In terms of rock-units, distinguished preferably by geographical names associated with the localities of the type sections.
>
> . . . paleontological and petrological zones, and economic units such as oil and water reservoirs, should also be shown and named separately in formal classification because they are not necessarily coincident with time- or rock-units although closely related to them.
>
> . . . we might imitate very approximately the form of paleontological nomenclature, age-names being used in the sense of genera which are subject to revision, and those of rock-units in the sense of species which are inviolate, if valid. For further information the names of the original author, the type area, and the date of publication might be added to the first reference in any given paper.
>
> Examples:
> (1) *Miocene Fars Series*, Pilgrim, S. W. Persia, 1908.
> (2) *Maestrichtian-Eocene Lapithos formation*, Bellamy and Jukes-Browne, Cyprus, 1905.

This last suggestion of a sort of Linnean binomial nomenclature for stratigraphy seems to the reviewer a little far-fetched, even for a "formal representation," though in many cases it would no doubt be advisable for the information it includes to be given, perhaps in a less stereotyped manner.

The author makes some further apposite comparisons between paleontology and stratigraphy, however, as shown in the following quotations.

> An objection frequently raised against this practice [of defining rock-units by means of geographical names] is that it threatens to flood geological literature with a mass of new terms. The same complaint might be made, with equal justification, by paleontologists, as the list of known fossil species ever increases; and the problem should be met in a similar manner in both cases, by a strict adherence to recognized rules of nomenclature which are designed to avoid redundancy and ambiguity, and by careful indexing and periodic publication of lexicons. . . .
>
> The author who names a rock-unit must specify a type section with all revelant data, and this, like a holotype fossil-specimen, serves as a standard of reference for future workers, who are bound to observe the law of priority. . . .
>
> Valid names of rock-units thus defined should present the important advantage of continuity and consistent usage in the literature; but there are "lumpers" and "splitters" in stratigraphy as in paleontology and superfluous formation names should go into synonomy, while other overwide units may be split up. . . .

A further suggestion for the avoidance of confusion resulting from lack of co-ordination

[1] P. O. Box 10, Auckland C1, New Zealand. Manuscript received, May 11, 1945.

between the work of independent investigators is the recognition of a central authority on stratigraphical terminology in each region, and a permanent world authority analogous to the "International Commission on Zoological Nomenclature." Henson further suggests that the respective Government Geological Survey departments should be the regional bodies, while he hopes that a world organization will emerge from the activities of the "International Commission on the Lexicon of Stratigraphy," elected at the Fifteenth International Geological Congress in South Africa, in 1929.

Since the avowed object of the paper is "to invite discussion," two points may be elaborated.

(1) *New formation names.* Besides the designation of a type locality, a photograph (if possible) and a measured section might also be specifically recommended for publication with the definition.

(2) *Law of priority.* Concerning this somewhat vexed principle various apparently conflicting opinions have beeen expressed.

Henson in the present paper seems to advocate a rigid application, using the phrases: "strict adherence to recognized rules of nomenclature," "bound to observe the law of priority," and "[names of rock-units] are inviolate, if valid."

Arkell,[2] after referring to "the monstrous and sterile problems of stratigraphical nomenclaure," states:

> Once we deviate from the original meanings of the terms and abandon the principle of priority, we lose our hold on the only life-line that can save us from the slough of conflicting opinions.

On the other hand, Schenck[3] has expressed himself thus:

> At times I wonder how far we must let priority go. . . . Priority alone will take us far afield and lead to absurd results, although I admit that priority is an important consideration.

Muller and Schenck[4] state:

> Thus, although they do not place unbalanced emphasis upon priority in stratigraphic nomenclature and although they think that original definitions must be weighted against usage, the writers submit that uniform usage of technical terms is conducive to mutual understanding.

Muller[5] writes:

> In stratigraphy, no hard and fast rules exist to aid one in determining which of the several stage terms is to be regarded as valid. It follows from general practice, however, that well-established usage should be given considerable if not deciding weight . . . .
>
> In most cases the application of the usage criterion is not difficult, but where two or more terms had been equally widely used for the same stratigraphical unit other factors had to be considered. In such cases, and when other conditions were more or less equal, the validity of the term was decided on the basis of priority.
>
> . . . But the rule of priority should not be blindly followed . . .

Finally, Wrigley and Davis,[6] in attempting to justify their departure from the law of priority, give as their reason:

> . . . Such a course [of adherence to priority] would lead to most disastrous confusion in the

[2] W. J. Arkell, *The Jurassic System in Great Britain* (Oxford University Press, 1933). 681 pp.

[3] H. G. Schenck, letter to the reviewer, April 7, 1942.

[4] S. W. Muller and H. G. Schenck, "Standard of Cretaceous System," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 27, No. 3 (March, 1943), pp. 262–78; 7 figs.

[5] S. W. Muller, "Standard of the Jurassic System," *Bull. Geol. Soc. America.*, Vol. 52, No. 9 (September 1, 1941), pp. 1427–1444; 2 folding tables.

[6] A. Wrigley and A. G. Davis, "The Occurrence of *Nummulites planatus* in England, with a Revised Correlation of the Strata Containing It," *Proc. Geol. Assoc.*, Vol. 48, Pt. 2 (1937), pp. 203–28; 2 pls.

Eocene of Western Europe. Almost every known term would have to be abandoned, or used in a sense quite different from what is current.

After giving examples of terms whose original meanings have been changed by later writers these authors state:

These are matters of usage, where "principles" are best abandoned if they lead to ridiculous or inconvenient conclusions. Some choice must be made, for there are more terms available than are required.

The divergence of opinion evident in these quotations may be more apparent than real, but in any case it constitutes a potent argument for the recognition and proper functioning of an international body to which doubtful points could be referred for decision.

It may be worth mentioning in this connection that in zoology the rigid application of the law of priority has proved very satisfactory and is almost universally accepted. Even where it might be thought that to change a well known name would cause confusion and difficulty, when necessary according to the law of priority such a change is favored by the great majority of zoologists. Davis and Lee,[7] for example, have recently written:

It frequently happens, particularly, with species which have some claim to economic importance or are notorious for some other reason, that systematists are prone to change the name of the species, to the consternation of lay usage. Workers on nontaxonomic problems, dissatisfied with the apparently frivolous changes of name, advocate a solution by means of comprehensive lists of *nomina conservanda*. Such changes of name, however, may usually be traced to past failure to apply the type concept and there is no more reason in taxonomy than in any other branch of biology to perpetuate definitely known errors of fact.

Article 25 of the "International Rules of Zoological Nomenclature"[8] is quite explicit and makes no exceptions for cases of "absurd results," "most disastrous confusion," or "ridiculous or inconvenient conclusions" (see preceding quotations from Schenck, and Wrigley and Davis). It is as follows.

The valid name of a genus or species can be only that name under which it was first designated on the condition:

(a) That this name was published and accompanied by an indication, or a definition, or a description; and

(b) That the author has applied the principles of binary nomenclature.

As well as this rule, however, the zoologists have a very important advantage over the stratigraphers, in the possession of a definite and universally approved starting point. Article 26 of the "Rules" is:

The tenth edition of Linne's *Systema Natura*, 1758, is the work which inaugurated the consistent general application of the binary nomenclature in zoology. The date 1758, therefore, is accepted as the starting point of zoological nomenclature and of the Law of Priority.

As regards stratigraphy, the joint committee representing the American Association of Petroleum Geologists, the Geological Society of America, the United States Geological Survey, and the Association of American State Geologists has also, in its report[9] prepared in 1932, approved in general the application of the law of priority. Article 9 states:

In the application of names to formations, the rule of priority, that the first geographic name applied to any unit and duly published shall be accepted, shall generally be observed; but a name that

[7] Consett Davis and D. J. Lee, "The Type Concept in Taxonomy," *Australian Journal of Science*, Vol. 7, No. 1 (August, 1944), pp. 16–19.

[8] Republished, with Summaries of the Opinions Rendered by the International Commission on Zoological Nomenclature, in *Proc. Biol. Soc. Washington*, Vol. 39 (July 30, 1926), pp. 75–104.

[9] G. H. Ashley *et al.*, "Classification and Nomenclature of Rock-Units," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 23, No. 7 (July, 1939), pp. 1068–88.

has become well established in use shall not be displaced, merely on account of priority, by a term not well known or only slightly used. A name that has previously been applied to any unit shall, in general, not be later applied to another unit.

In Articles 13 and 15 the principle is stated to apply also to the naming of groups and series, and members, lentils, and tongues.

After consideration of the position as it stands at present it seems to the reviewer, therefore, that besides the setting up (or recognition of existing) regional bodies, and an international authority, for the purpose of deciding questions of stratigraphical terminology, as advocated by Henson, there is another job to be done as well. This is the fixing of a starting point for the rigid application of the law of priority. There seem to be three possibilities:

1. Some date in the past,
2. Some date in the future,
3. Dates varying from region to region.

This last alternative would seem to be the wisest course in regard to the naming of local rock-units (as opposed to the divisions of geological time, terms for which cross the boundaries of regions, and would ideally eventually become world-wide in application); and the publication of an authoritative lexicon for any region would obviously be the appropriate time. The United States are fortunate in having such a lexicon already,[10] and for Africa also there is a similar work.[11] For other regions the further volumes in course of preparation under the auspices of the "International Commission on the Lexicon of Stratigraphy" would, when published serve the same purpose.

The mere publication of a lexicon would not, however, serve to indicate which of two or more existing conflicting names was to be preferred; specific pronouncements on all doubtful cases would be required. Names given after its publication would automatically be valid or not according to whether they were given in agreement with the recognized rules (including the law of priority) or not.

In regard to the names for the divisions of geologic time (time-stratigraphic terms) some other system will, perhaps, have to be devised. Priority may have to be subordinated to usage, as in the schemes proposed for the Jurassic and Cretaceous by Muller, and Muller and Schenck respectively (previously cited).

Above all, international agreement and the submitting of doubtful points to an authoritative body seem desirable, and the time is ripe for stratigraphers to unite in attaining these objectives before confusion becomes worse confounded.

[10] M. Grace Wilmarth, "A Lexicon of Geological Names in the United States (including Alaska)," *U. S. Geol. Survey Bull. 896* (1938). 2396 pp.

[11] *Lexicon de Stratigraphie, Vol. 1—Africa* (London, Thomas Murby and Co., 1938).

REVIEW OF PETROLEUM GEOLOGY IN 1944, BY F. M. VAN TUYL, W. S. LEVINGS, *ET AL.*

REVIEW BY WARREN B. WEEKS[1]
Bartlesville, Oklahoma

Review of Petroleum Geology in 1944, by F. M. Van Tuyl and W. S. Levings with the co-operation of various members of the faculty of the Colorado School of Mines. *Quarterly of the Colorado School of Mines*, Vol. 40, No. 2 (April, 1945), Golden, Colorado. 136 pp. including 4 figures and 4 portraits. Price, $1.00.

This, the third in a series of annual surveys of progress in petroleum geology, sponsored

[1] Phillips Petroleum Company. Review received, June 2, 1945.

by the research committee of the American Association of Petroleum Geologists, compiled and written by members of the faculty of the Colorado School of Mines, is essentially a topically arranged annotated bibliography of the literature published in 1944 pertaining to petroleum geology, which, in the opinion of the authors, is of general interest and importance.

In general outline the review follows closely the arrangement of the preceding review, with some changes in subtopics necessary to accommodate variations in the type of published papers. The 24-page bibliography following the manuscript is arranged under the same order of topics as is the body of the review. This is a list of those writings which contribute to, or are accounts of, the progress of the science of petroleum geology.

Of the above list, those items considered of general interest are annotated in the review covering 101 pages. The authors have injected personal views and accounts as well as those solicited from geologists who are leaders in various fields. In all they have come out with a full living and very readable story of the new developments and thought in petroleum geology.

The review is divided into five general topics. 1. "Important Developments of the Year," includes news items about geologists and geological meetings as well as reports on significant investigations pertinent to geologic knowledge. 2. "Advance in Petroleum Geology and Allied Subjects," covers new developments in petroleum geology, basic geologic sciences, geophysics, geobiology, spectroscopy, fluorescence, and petroleum engineering. This section discusses new maps and publications of general interest. The increasing importance of areo-photography is accented by the number of new publications thereon. There were a surprising number of papers discussing the future of the petroleum industry, reflecting the uncertainty of these times. In the field of geophysics there has been a notable increase in gravity work, compared with other methods, denoting the tendency toward study of broad regional structural conditions. 3. Under "Noteworthy Discoveries," is discussed new unsuspected geologic conditions recently brought to light, as well as general developments throughout the world. Of particular interest is the account of commercial production discovered in England. An expansion of this section would better balance the review. 4. "Production and Reserves," includes a general summary of production and reserve data, new concepts in estimating reserves, developments in substitutes for petroleum, and post-war requirements. 5. "Future of the Oil Industry," discusses articles related to expected consumption of petroleum, new uses and products, and the trend of future development.

These reviews will have a permanent and useful place in our literature. The excellent annotations will enable the geologist who has not the time for a full reading of the literature to obtain a general over-all picture of what is new and important in geology. They will further enable him, as well as the researcher, to pick out those papers which are pertinent to his problems and interests, facts which can not always be discernible in mere titles. The reviews will be of equal value to the student and teacher or to prospective authors who desire to gather material on any certain topic. A continuance of these reviews in the future will finally constitute a history of petroleum geology.

Those portions of the review which are of a statistical nature might well be enhanced by the addition of more figures. A few charts and graphs might be devised and carried forward from year to year to show comparative change.

It is apparent that such a review requires much labor and thought in the preparation. Much assistance could be furnished the authors by local committees throughout the world reporting for their digestion those geologic notes from the various areas or various fields of interest which are considered as of general interest.

RECENT PUBLICATIONS

ALBERTA

**Schedule of Wells Drilled for Oil and Gas to 1944*. 144 pp., chart of formations, index and development maps. Published by the Petroleum and Natural Gas Conservation Board, Calgary, Alberta (1945). Price, $2.00.

CALIFORNIA

"Asphalt and Bituminous Sandstone Deposits of Part of McKittrick District, Kern County, California," by Ben M. Page, Eiler L. Hendrickson, M. Dean Williams, and, Thomas G. Moran. *U. S. Geol. Survey Prelim. Map. 35*, Oil and Gas Investig. Ser. (July, 1945). Map, 31×44 inches. Scale, 1 inch equals 300 feet. Contains explanatory figures, sections, and brief text. For sale by Director, U. S. Geol. Survey, Washington 25, D. C. and Room 533,U. S. Post Office and Courthouse Building, Los Angeles, California. Price, $0.50.

CANADA

"Geological Reconnaissance along the Canol Road, from Teslin River to MacMillan Pass, Yukon: a Report and Map," by E. D. Kindle. *Canada Geol. Survey Paper 45-21* (1945). 26 mim. pp. Map is a blue-line print; scale, 1 inch equals 4 miles. Department of Mines and Resources, Mines and Geology Branch, Ottawa, Ontario, Canada.

COLOMBIA

*"El Precretaceo de Colombia" (Pre-Cretaceous of Colombia), by Daniel Trumpy. *Inst. Colombiano Petroleos Estudio Technico 366* (Bogota, April, 1945). 10 pp., sketch map and stratigraphic chart. In Spanish.

GENERAL

*"Problems in Geology and Geophysics" (Daly Volume), by 28 contributors. *Amer. Jour. Sci.*, Vol. 243-A (New Haven, Connecticut, 1945). 541 pp., illus. Contains the following.

"Strategy in Geology," excerpts from Professor Daly's Writings
"Correlation of Wisconsin Glacial Maxima," by Ernst Antevs
"Mechanics of Igneous Intrusion in New Hampshire," by Marland P. Billings
"An Estimate of the Surface Flow of Heat in the West Texas Permian Basin," by Francis Birch and Harry Clark
"Phase Equilibria Bearing on the Origin and Differentiation of Alkaline Rocks," by Norman L. Bowen
"Polymorphic Transitions and Geological Phenomena," by P. W. Bridgman
"Basement Control in Rocky Mountain Deformation," by Rollin T. Chamberlin
"Parallel Evolution in the Foraminifera," by Joseph A. Cushman
"The Hydrodynamical Factor in Ore Deposition," by G. Vibert Douglas
"Conjectures Regarding Volcanic Heat," by L. C. Graton
"Scale Models of Structures Related to Batholiths," by Frank F. Grout
"Variations in Physical Properties within the Earth's Crustal Layers," by Beno Gutenberg
"Leucitized Granite Xenoliths from the Potash-Rich Lavas of Bunyaruguru, South-West Uganda," by Arthur Holmes
"Protection of Harbors from Lava Flow," by T. A. Jaggar
"Types of Isostatic Adjustment," by Harold Jeffreys
"The International Gravity Formula," by Walter D. Lambert
"The Evolution of the Hydrosphere," by Alfred C. Lane

"Time Required for the Crystallization of the Great Batholith of Southern and Lower California," by Esper S. Larsen
"The Mechanics of Orogeny," by Chester R. Longwell
"Pre-Cambrian Problems in Western Australia," by H. E. McKinstry
"The Wasting Ores of a Small Planet," by D. H. McLaughlin
"The Olympic-Wallowa Lineament," by Erwin Raisz
"Air Photography in Geographical Exploration and in Topographical and Geological Surveying," by A. Hamilton Rice
"Further Studies of Bermuda," by Robert W. Sayles
"The Present Status of Daly's Hypothesis of the Alkaline Rocks," by S. J. Shand
"On the Astronomical Dating of the Earth's Crust," by Harlow Shapley
"Tin Deposits of Carguaicollo, Bolivia," by F. S. Turneaure and Russell Gibson

*"Subsurface Geologist," by Carl A. Moore. *The Link*, Vol. 9, No. 7 (Carter Oil Company, Tulsa, Oklahoma, July, 1945), pp. 1, 2, 10, 11; 6 illus.

*"The Nation's Reserves of Natural Gas," by E. DeGolyer. *Petroleum Engineer*, Vol. 16, No. 10 (Dallas, Texas, July 1, 1945), pp. 137–42.

KANSAS

*"Oil and Gas in Eastern Kansas," by John Mark Jewett and George E. Abernathy. *Kansas Geol. Survey Bull. 57* (Lawrence, 1945). 244 pp., 4 pls., 21 figs.

*"Stratigraphy of the Marmaton Group, Pennsylvanian, in Kansas," by John Mark Jewett. *Ibid., Bull. 58.* 148 pp., 4 pls., 2 tables.

MISSISSIPPI

*"Mississippi Becomes Major Oil Center," by George O. Ives. *Oil Weekly*, Vol. 118, No. 3 (Houston, June 25, 1945), pp. 33–42; 4 charts (production curves), table of proved salt domes, and historical sketches of Mississippi fields.

*"Mississippi, Where Persistence Pays," by John D. Todd. *Oil Weekly*, Vol. 118, No. 6 (Houston, July 16, 1945), pp. 49–52; one 2-page structure-contour map of Mississippi salt basin.

NORTH DAKOTA

*"Heavy Mineral Correlation of the Fox Hills, Hell Creek, and Cannonball Sediments, Morton and Sioux Counties, North Dakota," by Marie Louise Lindberg. *North Dakota Geol. Survey Bull. 19* (Grand Forks, 1945). Reprinted from *Jour. Sed. Petrology*, Vol. 14, No. 3 (Tulsa, December, 1944), pp. 131–43; 4 figs., 3 tables.

LOUISIANA

*"Ground-Water Resources of Jefferson Davis and Acadia Parishes, Louisiana," by T. B. Stanley, Jr., and J. C. Maher. *Louisiana Dept. Public Works* (1944). 93 pp., frontispiece, 10 figs., 10 pls.

WYOMING

*"Wyoming. Part 1, General Geologic Features," by Pierre La Fleiche. *Oil Weekly*, Vol. 118, No. 5 (Houston, July 9, 1945), pp. 30–33; 2 figs.

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 8 (AUGUST 1945), P. 1215

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The executive committee has approved for publication the names of the following candidates for memberwhip in the Association. This does not constitute an election but places the names before the membership at large. If any member has information bearing on the qualifications of these nominees, he should send it promptly to the Executive Committee, Box 979, Tulsa 1, Oklahoma. (Names of sponsors are placed beneath the name of each nominee.)

FOR ACTIVE MEMBERSHIP

Ronald Isaac Baker, Quito, Ecuador, S.A.
H. I. Tschopp, K. T. Goldschmid, Hans E. Thalmann
Chloe A. Browning, Tulsa, Okla.
Merritt H. Brown, John H. Nelimark, R. C. Tuttle
Clifford Winkler Byron, Houston, Tex.
J. H. Van Zant, R. C. Bowles, Wallace C. Thompson
Allan Cree, Casper, Wyo.
Guy E. Miller, Warren O. Thompson, A. S. Huey
Rudolph William Edmund, Oklahoma City, Okla.
Sherwood Buckstaff, W. C. Bean, Carl A. Moore
Alfred George Fischer, Tallahassee, Fla.
H. A. Sellin, H. G. Walter, Paul L. Applin
Henry Jones Gruy, Kilgore, Tex.
E. R. Scott, G. D. Thomas, E. P. Ogier
Tom D. Mayes, Tulsa, Okla.
John T. Rouse, William W. Clawson, Fred H. Wilcox
Emil Paul Thomas, Yazoo City, Miss.
Henry V. Howe, Harold N. Fisk, Chalmer J. Roy

FOR ASSOCIATE MEMBERSHIP

Thomas Jefferson Burnett, Jr., Austin, Tex.
Hal P. Bybee, Fred M. Bullard, L. C. Snider
Virginia Tolbert Fowler, Dallas, Tex.
C. G. Lalicker, Charles E. Decker, V. E. Monnett
Roald Andre Marin, Golden, Colo.
Ben H. Parker, J. Harlan Johnson, F. M. Van Tuyl
Thomas Robb Polk, Norman, Okla.
Tom L. Coleman, V. E. Monnett, C. G. Lalicker
Newton Joseph Rabensburg, Jr., Austin, Tex.
L. C. Snider, Hal P. Bybee, Don L. Frizzell

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 8 (AUGUST, 1945), PP. 1216-1224, 4 FIGS.

MEMORIAL

MARION HARBIN FUNK
(1899–1944)

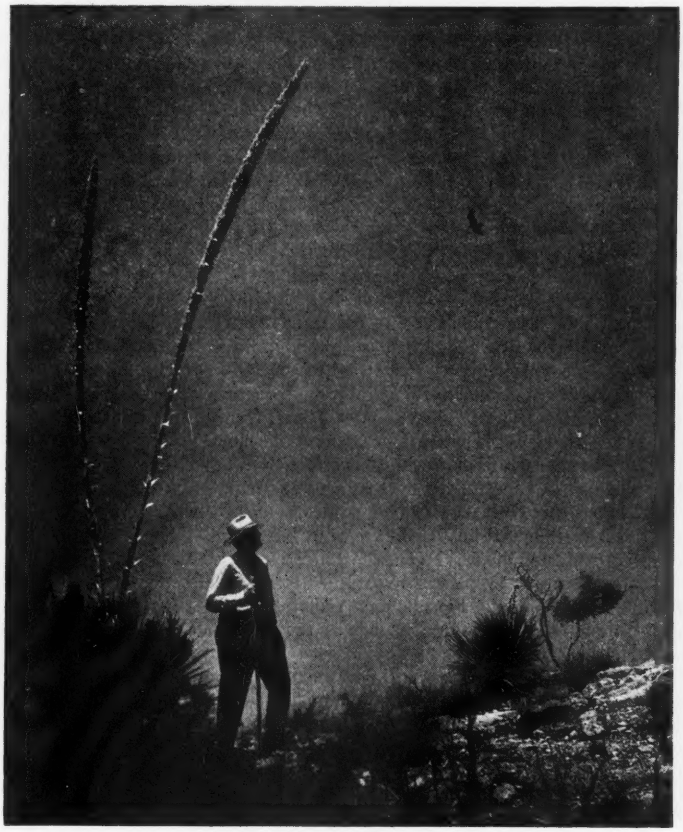
Early on the morning of December 30, 1944, Marion Harbin Funk died of cerebral hemorrhage at his home in Midland, Texas.

Marion was born on October 8, 1899, at Muscatine, Iowa, the son of Mr. and Mrs.

MARION HARBIN FUNK

Charles Marion Funk. His father still resides in Muscatine, where Marion's mother, who died when he was eleven years old, is buried. Love of his father and mother, probably magnified by her early death, was a very compelling force in his life. Few people, indeed, have been led, as Marion was, by love of family and determination to better the lot of that family as well as his own. After the death of his mother, Marion was sent to live with relatives in Red Cloud, Nebraska, and was in high school there at the time of the United States

declaration of war on Germany in 1917. He enlisted immediately in the Navy even though it was necessary for him to claim more years than he actually possessed. He served on the *U.S.S. New York* until given an honorable discharge as a result of shell-splinter wounds incurred in enemy action while he was signalling an emergency message to a torpedo boat. He was discharged in the spring of 1918 in a very weakened condition with orders to take



Marion Harbin Funk

life extremely easy for a matter of months if he wished to live. However, the manpower situation was critical and Marion went to work in a cement plant, at first for a few hours each day while his strength built up and later for longer periods at a time. Still physically weak, but undaunted in will, he entered the University of Nebraska, where he remained summer and winter alike holding odd jobs on the campus until he had finished a five years' course in petroleum geology and petroleum engineering in four years' time.

Characteristically, he decided to forego the satisfaction of commencement, the outward fulfillment of his immediate goal, in order to embark the sooner on his way to the next ob-

jective. Having satisfied all scholastic requirements, in 1925 he left for Venezuela where he worked a year for the Gulf Oil Corporation. Returning to the United States in 1926, he accepted a job with the Louisiana Oil Refining Corporation with headquarters in Shreveport. I first made his acquaintance in central Louisiana where he delayed a trip home from the field in order to stay with, and take care, of a new acquaintance suddenly uncomfortably ill. As I look back over my friendship with Marion I think this trait was also characteristic of him. Time after time I have known him to go out of his way unostentatiously to minister to the needs or comfort of persons who needed help. He was entirely happy in leaving to others the ministrations to the World's great and near-great, preferring in his truly humble and sincere way to confine his charity to those in real need.

Marion worked for the Louisiana Oil Refining Corporation until its reorganization and merger with the Cities Service in 1928. During the most of that period he was engaged in detailed and reconnaissance work in Louisiana, Arkansas, and Texas, but for 6 months he was employed in Trinidad, B.W.I., by the Trinidad Oil Fields, Inc., an affiliate of the Louisiana company.

In 1928, he was district geologist for the Pure Oil Company at El Dorado, Arkansas, and in 1929 he was in the employ of the American Oil Company, Oklahoma City, Oklahoma, as production geologist and appraisal engineer.

In March, 1930, he went to work for the Twin State Oil Company, Tulsa, Oklahoma. In August, 1931, he was transferred to the Dallas Office of the parent organization, the Sun Oil Company. His first assignment with the Sun was preliminary magnetic reconnaissance work, but in February, 1933, he was transferred to the geological department and assigned the supervision of a rather ambitious program of geophysical and subsurface investigations in the Rio Grande Valley of Texas. Here for a time competition between the major companies was keen and his extreme conscientiousness was nearly his undoing for it led him to spend himself beyond his strength in order that the job assigned to him might be finished in time for his company to participate on a basis of equal geological knowledge of the country with rival companies, some of whom had been working the area for a considerably longer time. To the credit of the Sun Oil Company and as a mark of its high esteem for Marion, he was given an extended leave of absence with pay, and, recovering his health during 1934, he was re-assigned to reconnaissance work in Arkansas, East Texas, Mississippi, Georgia, Florida, and Alabama.

After completing this assignment, he was sent to Illinois for a short time to look over and report on the Illinois-Indiana-Ohio oil boom then at its height.

Returning from this assignment, he was sent as reconnaissance geologist to the West Texas-New Mexico Permian basin. For a time he had headquarters in Lubbock, where he met, fell in love with and married Miss Freda Lucille Creager, a registered nurse then in training at West Texas Hospital where she nursed him through a fractured spine and other injuries incurred in an automobile wreck. The wedding took place in Muleshoe, Texas, on March 23, 1939. After a short honeymoon in the New Mexico mountains, the newlyweds returned to Lubbock where they resided for two years until Marion was transferred to Midland, as district geologist in the Permian basin.

Here began the busiest time of Marion's life. Again his conscientiousness led him to burn the candle at both ends in an endeavor to keep his company, with a comparatively small staff, abreast the wave of development which began in earnest in 1936.

As the war came on, the pressure increased until in early 1944, as a result of a heart attack brought on by a circulatory trouble induced by overwork, he was confined to his home for several weeks. He was told by his physicians that he must rest and was persuaded somewhat against his will by his family and friends to take a vacation in Colorado. After an all-too-short rest, Marion felt compelled to return to his duties, but on the way back he was intercepted by his physicians and requested to remain in Levelland at the home of

his wife's people for a month or two to prevent his early return to work where the basic causes of his trouble lay. Here, he slowly improved in general health until again forced into the hospital in Lubbock for an appendectomy, after which he rallied and had made plans to go to Boston for treatment of his circulatory trouble when his death occurred. His passing, though a tremendous shock to his family and friends, was accompanied by a minimum of suffering.

He is survived by his widow, Mrs. Freda Creager Funk; a son, Charles Marion, and a daughter, Marcia Ruth, children of a former marriage; and his father and two sisters.

Marion was a member of the American Association of Petroleum Geologists, having joined in 1924, and of the American Institute of Mining and Metallurgical Engineers. He was also a member of the Woods W. Lynch Post of the American Legion and in line with the rest of his life was particularly active in that phase of Legion work directed toward care for the needy and unfortunate of the community. Before it became necessary to devote all waking minutes to office work he had been active in church work. He was a member of the First Baptist Church of Shreveport, Louisiana, and had served as a deacon of that church.

Surely, he looks back from the heights his great-hearted, simple and loyal soul has enabled him to attain, happy in the knowledge of the security and love with which he has surrounded his children. Just as surely, his greeting from the King of Kings must be "Well done, thou good and faithful servant."

DANA M. SECOR

MIDLAND, TEXAS
May 8, 1945

CURTIS J. HESSE
(1905–1945)

Curtis J. Hesse, curator of the Museum of the Agricultural and Mechanical College of Texas, was born on September 28, 1905, in Wamego, Kansas, and died at Bryan, Texas, May 12, 1945, after recurring heart attacks. He is survived by his mother, Mrs. C. V. Hesse and a brother, C. G. Hesse, both of Lawrence, Kansas.

Mr. Hesse entered the field of paleontology when he was 14 years of age, being connected with the Museum of Paleontology at the University of Kansas, and held this position until 1929. During the time he was connected with the University of Kansas Museum, he completed work for his Bachelor of Arts degree which was conferred by the University in 1927. In 1929, he went to the University of California on a teaching fellowship and later became laboratory and field assistant for the Museum of Paleontology. During his connection with the University of California, he received his Master of Arts degree in 1933.

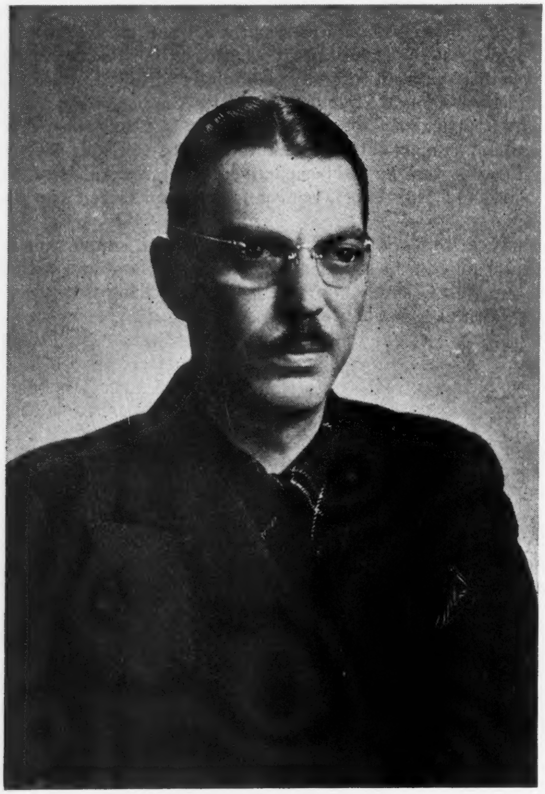
In 1938, Mr. Hesse came to Texas A. & M. as assistant curator of the Museum and in 1943 he was made curator, which position he held until the time of his death. In addition to duties with the operation of the Museum and field trips over Texas and other states in its interest, he gave a portion of his time to work on the teaching staff of the department of geology. The esteem in which he was held by his colleagues and students and the papers he has contributed to important scientific journals are a tribute to his scientific accomplishment and inspirational force.

Even though Mr. Hesse carried a full schedule with his teaching load and work at the Museum, still he found time for numerous articles on the results of research which he was conducting in different phases of geology. He was secretary of the A. & M. chapter of the American Association of University Professors, treasurer of the Texas Academy of Science, and held membership in the American Association of Petroleum Geologists, American Association for the Advancement of Science, Geological Society of America, American Society of Vertebrate Paleontologists, Texas Archeological and Paleontological Society,

Sigma Xi, Texas Geographic Society, American Society of Mammalogists, and American Society of Economic Paleontologists and mineralogists.

His services to these organizations are evidence of his willingness to contribute beyond the line of duty to the advancement of scientific endeavor.

To his scholarship was added an intense interest in the development of good citizen-



CURTIS J. HESSE

ship in American youth. He gave much of his time to fostering Boy Scout activities in this section of the state and in this capacity became a leader. He was scoutmaster for Troop 102 of College Station, which maintained headquarters in the Museum. Mr. Hesse had the reputation of being one of the best and most efficient scoutmasters in this area and his troop was regarded as a model for proper Scouting activities.

Being always ready to address the boys and girls of Bryan and College Station schools, he was frequently called upon and prepared for these talks in the spirit of embracing an opportunity to turn the thoughts of youth in the right direction.

Mr. Hesse possessed the admirable characteristics of being trustworthy, helpful, friendly, courteous, kind, and cheerful. With these traits, it is not extraordinary that his personality won him the friendship of his associates.

HAROLD VANCE

COLLEGE STATION, TEXAS
May 26, 1945

ION POPESCU-VOITEŞTI
(1876–1944)

On October 4, 1944, Professor Ion Popescu-Voiteşti, died as the result of injuries sustained from a fall while hunting near his home, in Voiteşti, District of Gorj, in the western part of Roumania, where he had lived since retirement in 1941 from the chair of geology in the University of Bucharest. Only his wife, Ana, and a sister survive him.

Professor Voiteşti was born in Voiteşti, November 18, 1876. He entered the University of Bucharest in 1895, studied medicine a time but majored in natural science, having been a pupil of the late Professor Ludovic Mrazec. After teaching in the lyceums of Slatina, Târgul Jiu, Tulcea, and Câmpul Lung-Muscel, he went abroad to complete his geological studies in Vienna and Paris, studying under Uhlig and Diener, and completing his doctorate under Professor Haug in 1910. He was then made geologist in the Roumanian Geological Institute and from 1910 to 1919 also had the chair of natural sciences in the Matei Basarab Lyceum of Bucharest. In 1919 he gave up these positions to take the chair of geology and paleontology at the University of Cluj which he held until his appointment in 1936 as professor of geology at the University of Bucharest. He saw service in the war against Bulgaria in 1913 and much active service as Major with the Roumanian Army 1916–1918 in its campaign against the forces of the Central Powers.

His familiarity with geological conditions of practically all of Roumania, as well as of the neighboring parts of Poland and Bulgaria, made him an outstanding authority. His published works in Roumanian and French exceed 135, the most of which deal with the structural geology of the Carpathian and Subcarpathian regions.

Murgoci was probably the first to recognize the principle of over-thrusts in the tectonics of the Carpathians, but Voiteşti was certainly the first to recognize it in the Eastern Carpathians. He delivered an important paper on this subject before the Association of Carpathian Geologists in Prague in 1930. Perhaps his most important work is "Evoluţia Geologico-Paleogeografica a Pământului Românesc" which appeared in 1935. It is a very well presented synthesis of the geology as well as the paleogeography of Roumania. He was a recognized authority and published many works on the salt masses of Roumania and their important role in structure problems in connection with oil accumulation. He contributed to the salt-dome volume of this Association and to the symposium on salt intrusions when he attended the International Petroleum Congress in London in 1923.

As official delegate he attended the International Geological Congress in Brussels in 1922, the Centennial of the Geological Society of France in 1930, and the International Congress of Mining, Metallurgy, and Applied Geology in Belgium, where he received the Albert medal. He was one of the principal founders of the Association of Carpathian Geologists, attending its congresses at Lwow in 1925 and Prague in 1930. He also attended the International Geological Congress at Cairo in 1924 and at Madrid in 1926.

For a period of more than 20 years, he did field work during the summer months for the Romano Americana, a Standard Oil Company of New Jersey subsidiary in Roumania and his advice was sought by many State and private undertakings.

Professor Voiteşti had a very large circle of friends in Roumania and abroad. He made many lasting friendships both as professor and as colleague in geology and exercised a

profound influence upon his classes. The writer knew him in his home, with his students, and in the field for many years and can say he was universally loved by all who knew him. He had command of French, German and English, which gave him a more than average facility to learn the ideas of foreign geologists. But his outstanding trait of straightforwardness and wholesome honesty would have made him loved in any walk of life. His humor never failed him. He was a patriot but no chauvinist; a learned scientist who was never dull; a busy hard-working professor who always found time to get acquainted with his students or to exchange pleasant nonsense with small children.

His home life was ideal, for his wife was also an educator, having many interests in common with her husband outside of the home. She assisted him ably in producing many works; his text book *Elemente de Paleontologie* was dedicated to her.

Roumania has lost one of her pioneer scientists, and the American Association of Petroleum Geologists has lost a distinguished member and contributor. The writer and many other geologists have lost a very dear friend.

WALTER M. SMALL

BUCHAREST, ROUMANIA
April, 1945

CHARLES TOWNSEND KIRK
(1876–1945)

Dr. Charles Townsend Kirk passed away on June 1, 1945, in Tulsa, Oklahoma, at the age of 68 years.

His immediate family mourns the loss of a devoted husband and a loving, sympathetic father. He is remembered by fellow geologists as an earnest teacher, an able author, and as a conscientious and careful worker in field and office. In his capacity as consulting geologist, his business associates think of him as an honorable, loyal, and faithful adviser. In his church and in his daily round of activities, his colleagues recall his kindly interest in them, and his thoughtful unselfishness.

Dr. Kirk was born in Francisco, Indiana, on June 22, 1876. He came of American stock, and was proud of the fact that he descended from veterans of the Revolutionary and Civil wars.

When he was fourteen years old, he moved to Oklahoma with his parents, brother, and sisters. The family settled on a farm nine miles southeast of Oklahoma City where Charles attended the neighborhood rural school. Later he attended the preparatory school of the University of Oklahoma at Norman. His desire for an education is evidenced by his effort in riding his bicycle twice daily over the sixteen miles of country roads which lay between his home and Norman. In his college course, he was self-supporting, at first through his work as commissary of a students' boarding club, and later as part-time teacher in the Norman high school. He demonstrated his scholastic ability by completing a four years' course of college work in three years. He received his Bachelor of Science degree in 1904 and Master of Arts degree in 1905.

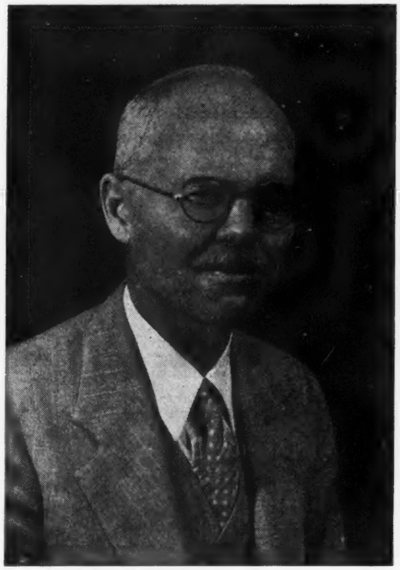
After a year of teaching in Oklahoma City, he married Miss Bessie Keller, his boyhood sweetheart, in August, 1906, and the couple moved to Butte, Montana, where he was instructor in geology in the Montana State School of Mines for two years.

In line with his deep-seated ambition to be a geology teacher with the highest qualifications, Kirk, in 1908–1910, attended the graduate school of the University of Wisconsin, where he had a teaching fellowship. He received his Doctor of Philosophy degree in 1911, after having been elected to both Phi Beta Kappa and Sigma Xi.

After three years as assistant professor of geology at Hunter College, New York (1910–1913), Dr. Kirk became professor of geology at the University of New Mexico,

and State geologist of New Mexico, where he remained from 1913 to 1917, after which he left the teaching field to enter commercial work in Oklahoma. His first business connection in Oklahoma was with the Kanola Oil Company, which was organized by L. L. Hutchinson, W. B. Blair, Ira Montgomery, and Dr. Kirk. In 1919 he made a trip to South America for the Atlantic Oil Company. Upon his return to Tulsa in 1920, he became a consulting geologist. In 1922, the firm of Kirk and Hoover, consulting geologists, was formed, which was active for several years.

At various times throughout Dr. Kirk's career, beginning with his Montana days, he was connected with the United States Geological Survey. His publications include the following.



Charles Townsend Kirk

"A Preliminary Report on the Contact of the Permian with the Pennsylvanian in Oklahoma," *Oklahoma Dept. of Geol. and Nat. Hist. Bien. Rept.*, Vol. 3 (1904), pp. 5–14.

"Gold, Silver, Copper, Lead, and Zinc in Montana," *U. S. Geol. Survey Min. Resources, 1907* (1908), pp. 312–37.

"Conditions of Mineralization in the Copper Veins at Butte, Montana," *Econ. Geol.*, Vol. 7 (1912), pp. 35–82.

"The Geology of the Gallup Basin, New Mexico," *New Mexico Univ. Bull. 76*, Geol. Ser., No. 3 (1914), pp. 26–68.

"Certain Structural Features in the Coal Fields of New Mexico" (abstract), *Bull. Geol. Soc. America*, Vol. 26 (1915), pp. 405–6.

"Tungsten Deposits of Boulder County, Colorado," *Min. Sci. Press*, Vol. 112 (1916), pp. 791–95.

"Significant Features of Western Coal Deposits," *Bull. Southwestern Assoc. Petrol. Geol.*, Vol. 1 (1917), pp. 148–51.

"Notes on Sequoyah County, Oklahoma," *Bull. Amer. Assoc. Petrol. Geol.*, Vol. 5, No. 4 (1921), p. 503.

(With Weirich, T. E.), "Steep Subsurface Folds versus Faults," *Bull. Geol. Soc. America*, Vol. 38, No. 4 (December, 1927), pp. 577–89; *Pan-Amer. Geol.*, Vol. 47, No. 2 (March, 1927), pp. 153–54.

(With others), "Subsurface Geology and Oil and Gas Resources of Osage County, Oklahoma," Pt. 2, *U. S. Geol. Survey Bull. 900-B* (1939), pp. 47–82; Pt. 7, *ibid., Bull. 900-G* (1941), pp. 237–68; Pt. 8, *ibid., Bull. 900-H* (1941), pp. 269–302.

Dr. Kirk was interested in several professional and scientific organizations. He was a charter member of the American Association of Petroleum Geologists. He belonged also to the Geological Society of America, the American Institute of Mining and Metallurgical Engineers, The New York Academy of Science, the New Mexico Association of Science, and the Tulsa Geological Society, of which he was president in 1923. He was listed in *Who's Who in America*. His activities extended beyond the bounds of his profession. He was an active member of the First Christian Church of Tulsa, and was a 32d-degree Mason.

Dr. Kirk is survived by his widow, Mrs. Bessie Kirk; three daughters, Miss Florence Kirk of the home, Mrs. Ross J. Lyons, who lives in California, and Mrs. F. D. Baker, of Tulsa; and a son, David K. Kirk, who lives in Pennsylvania.

Throughout Dr. Kirk's busy life, his work was activated by his philosophy of being temperate in all things. No more fitting tribute can be paid to his memory than was expressed by Dr. Claude Hill in the funeral sermon in which he spoke of Dr. Kirk as being "truly one of God's gentlemen." His friends count it a privilege to have known Dr. Kirk.

LUTHER E. KENNEDY

TULSA, OKLAHOMA
July, 1945

BULLETIN OF THE AMERICAN ASSOCIATION OF PETROLEUM GEOLOGISTS
VOL. 29, NO. 8 (AUGUST, 1945), PP. 1225-1232

AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

MARTIN G. EGAN has closed his office in Mt. Carmel, Illinois, where he has been engaged in consulting work for the past 5 years, to accept a geological position with the Venezuelan Atlantic Refining Company in Caracas, Venezuela.

GEORGE L. (LEE) ELLIS, recently with the Petroleum Administration for War, Washington, D. C., has joined the geological department of the Stanolind Oil and Gas Company, to be stationed at Tyler, Texas.

VICTOR OPPENHEIM, consulting geologist, has moved from Lima, Peru, to Bogotá, Colombia. His address is Apartado 381. He is working in connection with petroleum concessions in Colombia, Ecuador, and Peru.

CLENON C. HEMSELL has resigned his position as chief geologist for the Shamrock Oil and Gas Corporation, and has accepted the position of executive assistant with J. M. Huber, Incorporated. He is located at Borger, Texas, effective August 1.

JOE NETICK, recently with the Pure Oil Company, San Antonio, Texas, is with the Orinoco Oil Company, Apartado 168, Maracaibo, Venezuela.

OLIVER P. NICOLA, JR., is employed by the Phillips Petroleum Company, Wichita Falls, Texas.

Lieutenant GEORGE TAYLOR MCINTYRE, U.S.N.R., is stationed in the Philippine Islands.

Lieutenant Colonel HUBERT G. SCHENCK, who in peace-time is professor of geology at Stanford University, has recently been awarded the Bronze Star Medal "for meritorious achievement in connection with military operations against the enemy in New Guinea and the Philippine Islands, from 20 October, 1944 to 20 April, 1945." He is now connected with the office of the chief engineer at General Headquarters in Manila.

The Wyoming Geological Association, Casper, Wyoming, completed its technical program, preceding the summer field season, with the following speakers: on May 26, N. W. BASS, of the United States Geological Survey at Denver, Colorado, spoke on "Subsurface Stratigraphy of the Four-Corners Region"; and on May 31, JOHN DAVID LOVE, of the U.S.G.S. at Laramie, Wyoming, spoke on "Tertiary and Cretaceous Formations of the Wind River Basin." A dinner-dance was held at the Casper Country Club on May 12, sponsored by the geologists, and attended by a number of scouts and other oil men.

WILLIAM G. KANE is still engaged in the procurement of strategic minerals for war purposes, as chief of the field staff of engineers and geologists for the United States Commercial Company at Mexico City, Apartado 711. His home address is 38 Alta Vista, Villa Obregon.

RALPH H. HOWE, formerly with the Caribbean Petroleum Company in Venezuela, is geologist with the California Company, 1818 Canal Building, New Orleans, Louisiana.

C. C. ANDERSON, of the United States Bureau of Mines, was recently transferred from the position of engineer-in-charge of the Exell helium plant, Amarillo, Texas, to assistant chief of the Petroleum and Natural Gas Division at Washington, D. C.

Newly elected officers of the Mississippi Geological Society for the year ending May 1946, are: president, J. B. STOREY, Union Producing Company; vice-president, F. F. MELLEN, consultant; secretary-treasurer, J. B. WHEELER, Stanolind Oil and Gas Company; all at Jackson.

J. J. GALLOWAY, professor of geology and paleontology in Indiana University, has been selected by the War Department to be professor of geology and branch head of geology in the Army University Study Center in the European Theater of Operations. The Army University will give instruction in most college subjects to qualified soldiers in the Army of Occupation. Galloway will probably be located in France. He has contracted to stay a year.

Captain ADOLPH T. EBERHARDT, of the Shell Oil Company, Inc., Evansville, Indiana, was killed in an airplane accident early in 1944. He was with the Public Relations Office, Robins Field, Georgia. Eberhardt, was born at Springdale, Wisconsin, June 4, 1908. He graduated from the University of Wisconsin, a Bachelor of Arts in 1931. He had been employed by the Shell Oil Company since 1937. He joined the A.A.P.G. in 1942.

E. W. RUMSEY has left the Shell Oil Company, Inc., at Amarillo, to become district geologist for the Bay Petroleum Corporation at Wichita Falls, Texas.

JOHN F. BRICKER, of the Humble Oil and Refining Company, Houston, Texas, has been appointed chief scout for his company.

GEORGE C. HARDIN, JR., has resigned from the United States Geological Survey for whom he has acted as party chief in the western Kentucky fluorspar field and has accepted a position as geologist and superintendent for the Carter-Gragg Oil Company, Palestine, Texas.

FLOYD M. AYERS, recently with the International Petroleum Company at Guayaquil, Ecuador, is with the Standard Oil Company of Cuba, at Santiago de Cuba.

JOHN L. RICH, chairman of the department of geology and geography of the University of Cincinnati, has returned after completing 3 months of work in China for the China Natural Resources Commission.

ROBERT J. STEEL, consultant and independent operator, is at the Connellee Hotel, Eastland, Texas.

JAMES N. HOCKMAN is with the Central Pipe Line Company, Box 180, Salem, Illinois.

Lieutenant JOHN W. FLUDE, of Columbus, Mississippi, is in the Naval Reserve, Box 330, Galveston, Texas.

Major B. M. SHAUB, on leave from Smith College, Northampton, Massachusetts, is in the Ordnance Department, 95 State Street, Springfield, Massachusetts.

Lieutenant NORMAN M. NICHOLS, of Oxnard, California, is in the Naval Supply Depot, SPDC., Pearl Harbor, Hawaii.

Lieutenant EDGAR R. BREED, JR., of the Shell Oil Company, Inc., Centralia, Illinois, has been officially listed as dead, a year after having been reported as missing in action when a ship was sunk. Breed was born at Medford, Massachusetts, October 9, 1915. He graduated from Harvard College, as a Bachelor of Science, in 1938. He became an associate in the A.A.P.G. and a junior geologist with the Shell Oil Company in 1939.

Lieutenant Colonel HERBERT MAYNARD GOODMAN, of Coin, Iowa, is with the Amphibian Engineers, APO 70, San Francisco.

Lieutenant JULIAN HOWES, U. S. Navy, may be addressed at 1501 U Street SE., Anacostia 20, D. C.

Major PHIL D. HELMIG, of Roswell, New Mexico, is on the General Staff, 6th Army Headquarters, c/o P.M., San Francisco.

Captain JOHN HARVEY HERD, of Post, Texas, is in the Air Force, APO 520, New York.

Major WILBUR B. SHERMAN is in the AAF Weather Service.

Lieutenant ALFRED NORMAN McDOWELL, of Texarkana, Arkansas, is in the Naval Reserve, Instrument Low Approach Project, NATTC, Gainesville, Georgia.

Corporal T. A. CLOTE, of the Sunray Oil Company, Tulsa, Oklahoma, is in the Air Corps, Squadron O, Box 879, MacDill Field, Tampa, Florida.

AUBREY H. GARNER, of DeGolyer and MacNaughton, Dallas, Texas, may be addressed c/o U. S. Embassy, Rio de Janeiro, Brazil.

Lieutenant JAMES M. WHATLEY, of Shreveport, Louisiana, is doing photographic interpretation work in the Pacific area.

GILBERT L. BROWN, formerly with the Phillips Petroleum Company at Midland, is with the Forest Development Corporation, San Antonio, Texas.

FAY COIL is with the Superior Oil Company, Midland, Texas. He has returned to reserve status as Major in the Coast Artillery Corps.

Major JOHN LAWRENCE LESTER, of Alliance, Ohio, is with the Field Artillery, APO 103, New York.

Captain CLINTON C. KEARNY, of San Antonio, Texas, is a pilot in the Air Corps, 829 Bomb. Squadron, 485th Bomb. Group, Sioux Falls, South Dakota.

Lieutenant L. CLARK KNIGHT, of Great Bend, Kansas, is in the Navy Reserve, 48 Alabama Drive, Waylyn Navy Yard, South Carolina.

Lieutenant DAN E. FERAY, of Beaumont, Texas, is in the Air Corps, Photo Unit, Jefferson Barracks, Missouri.

Apprentice Seaman HERMAN W. FERGUSON, of the Tennessee Division of Geology, Nashville, is in the Navy, Company 903, USNTC, Great Lakes, Illinois.

Captain JOSEPH A. FRYOU, of Bay City, Texas, is in bombing activity, APO 247, c/o P.M., San Francisco.

A. I. LEVORSEN, president of the Association in 1935 and for many years an independent operator and consulting geologist of Tulsa, Oklahoma, has moved to California to become chairman of the department of geology at Stanford University.

D. F. SANDIFER has left the Stanolind Oil and Gas Company at San Antonio, Texas, and is now with the Transwestern Oil Company in the same city.

A. N. MACKENZIE has resigned from the Petroleum Administration for War. He is now associated with the British-American Oil Company, Ltd., as manager of exploration with headquarters in Calgary, Alberta, Canada.

REGINALD G. RYAN, formerly at Baton Rouge, is district geologist for the Ashland Oil and Refining Company at Shreveport, Louisiana.

ERIK K. WARING has changed his address from Petroleos Mexicanos, Mexico City, Mexico, to DeGolyer and MacNaughton, 1000 Continental Building, Dallas, Texas.

H. H. VAN AKEN has left the Permian Oil Company, Lubbock, Texas. His address is 436 Holland Avenue, Los Angeles, California.

JOHN D. DOUGLAS, of the Mene Grande Oil Company, has been transferred from Caracas to the Maracaibo office of the company. His address is Apartado 234, Maracaibo, Venezuela.

HOLLIS D. HEDBERG has been transferred from Barcelona to the Caracas office of the Mene Grande Oil Company, Apartado 709, Caracas, Venezuela. Hedberg is the Association regional editor in South America.

J. MARVIN WELLER has left the Illinois Geological Survey, Urbana, where he has been geologist and head of the stratigraphy and paleontology division, to become professor of invertebrate paleontology in the department of geology at the University of Chicago, Chicago 37, Illinois. Weller is editor of the *Journal of Paleontology*, published by the Society of Economic Paleontologists and Mineralogists.

The executive committee of the Association met at the Stevens Hotel, Chicago, for a two-day business session, July 8 and 9. Officers present were: president M. G. CHENEY, of Coleman, Texas; past-president IRA H. CRAM, of Chicago; vice-president M. G. GULLEY, of Pittsburgh; and editor GAYLE SCOTT of Fort Worth.

Captain LOUIS J. WILBERT, JR., recently in the department of geology at Louisiana State University, Baton Rouge, is in the Air Corps.

Lieutenant JAMES LEE KERR, of Nowata, Oklahoma, is in the Naval Air Corps: Aerology, NAAS, Kingsville, Texas.

Captain LEON R. VESELY, of the Amerada Petroleum Corporation, may be addressed: O.C.O. Requirements Div., Room 1C564a, Pentagon, D. C.

ELIZABETH A. WATSON is with the Union Oil Company, Los Angeles, California.

Lieutenant WILLIAM D. LEWIS, of Pasadena, California, is in the Navy.

A. G. MCCARVER, of Midland, Texas, is in the employ of the Seaboard Oil Company, 1400 Continental Building, Dallas.

HARALD W. C. PROMMEL, consulting geologist and mining engineer, 731 Downing Street, Denver, Colorado, has been engaged in mining and engineering practice since his work on lead and zinc for the United States Bureau of Mines at Leadville, in 1943.

ALBERT I. GREGERSEN is vice-president and manager of the Danish American Prospecting Company, 6 Gammeltorv, Copenhagen, Denmark. The company is resuming its exploration which was interrupted because of the war.

F. R. S. HENSON, senior subsurface geologist of the Iraq Petroleum Company, Ltd., is in the United States for a visit of 2 or 3 months. His address is the Near East Development Corporation, Room 2611, 26 Broadway, New York 4, N. Y. He reports a growing desire for cooperation in scientific effort in connection with the exploration and development of the mineral resources in the eastern Mediterranean countries. Discussions have been in progress among the geologists of the Middle East, with a view to the formation

of a geologists association. An inaugural meeting of geological delegates from several countries was scheduled to be held in Jerusalem a year or so ago but it was necessarily postponed because of the military situation.

WALLACE E. PRATT, director and member of the executive committee of the Standard Oil Company (New Jersey), has retired. He began work for the Standard companies as chief geologist for the Humble Oil and Refining Company in Houston, Texas, in 1917. In 1923 he became a director of the Humble, and in 1933 its vice-president. In 1937 he resigned, to become a director and member of the executive committee of the parent company in New York, and 1942 he became vice-president, a position which he relinquished in 1944. Pratt was president of the A.A.P.G. in 1921, and he is now chairman of the trustees of the Association revolving publication fund. In March, 1945, he was the first recipient of the Sidney Powers Memorial medal.

Lieutenant HARLAN W. NEWELL, whose home address is 2692 Landon Road, Shaker Heights, Cleveland, Ohio, is overseas in the Field Artillery.

S. SPENCER NYE, of the United States Geological Survey, recently presented a paper, "Orogeny of the Mexican Plateau and Its Relation to Ore, Oil, and Ground Water," before the Geological Society of Washington, D. C.

Lieutenant NORMAN C. SMITH, of Somerville, New Jersey, may be addressed: P.I.C., N.A.S., Anacostia, Maryland.

T. WAYLAND VAUGHAN, of the United States National Museum, Washington, D. C., has been notified by the National Academy of Sciences, of the Mary Clark Thompson Medal and honorarium for 1945 in "recognition of outstanding achievement in his purposeful and ingenious coordination of observations and generalizations made in and bearing on the fields of stratigraphic geology and paleontology."

JAMES R. DORRANCE was appointed chief geologist of The Texas Company, Pacific Coast area, effective March 1, 1945, with headquarters in Los Angeles, California.

E. STILES, of Hamilton, Texas, has been appointed business manager of the Society of Exploration Geophysicists, succeeding J. F. GALLIE, whose full-time duties with the Arkansas Oil and Gas Commission, El Dorado, Arkansas, have forced his resignation as manager of S.E.G.

Major BENNETT FRANK BUIE, whose home address is Patrick, South Carolina, has returned from Persia for 45 days of home duty and reassignment. Major Buie has been in the Army Engineers.

IAN CAMPBELL, associate professor of geology at the California Institute of Technology, Pasadena, is on leave, serving as a "pilot" instructor in the University of California War Research Group.

JOSEPH A. CUSHMAN, Laboratory of Foraminiferal Research, Sharon, Massachusetts, has recovered his health and continues in research. He has published his 450th paper.

KIRTLEY F. MATHER, professor of geology at Harvard, has published "The Needs of Man" in *Science*, New Series, Vol. 101 (1945), pp. 198–200. This is a discussion of a criticism of his recent book, *Enough and To Spare*. He was recently made an honorary fellow of the Rochester Academy of Arts and Sciences.

WILLIAM F. JENKS has resigned as geologist for Cerro de Pasco Copper Corporation, Lima, Peru, to accept appointment by the United States State Department as visiting professor in geology at the Universidad Nacional de San Agustin in Arequipa, Peru.

Colonel WILSON G. SAVILLE, of the Gravity Meter Exploration Company, Houston, Texas, is in the Engineers Division, Supreme Headquarters. He has received the order of the British Empire Award.

Major ROE AUSTIN GRAY is with the Army Engineers. His home address is 1373 Forty-Second Street, Sacramento, California.

Major JOSEPH NEELY, of the Magnolia Petroleum Company, Dallas, Texas, is in the Air Corps, CATS Yale University, New Haven, Connecticut.

Lieutenant KENNETH C. ANDERSON, of 901 East Linwood Boulevard, Kansas City, Missouri, is in the Army Engineers.

WILLIAM T. THOMAS, recently with the R. W. Fair Interests at Duncan, Oklahoma, is with the Trowbridge Sample Service, 333 Ricou-Brewster Building, Shreveport, Louisiana.

RUSSELL FARMER is district geologist for the Stanolind Oil and Gas Company at Midland, Texas.

Lieutenant J. TATE CLARK, of the Phillips Petroleum Company is in the Navy.

RAY C. LEWIS has resigned his position as district geologist of the Texas Gulf Coast district for the Stanolind Oil and Gas Company to accept one as chief geologist for the Houston Oil Company of Texas, with headquarters in Houston.

W. J. LANG, formerly with the Carter Oil Company, is with the Creole Petroleum Corporation, Caracas, Venezuela.

E. J. HANDLEY, formerly in charge of geophysics for the British American Oil Producing Company at Tulsa, is now with the Shell Oil Company, Inc. He was recently transferred from Denton, Texas, to Tulsa, Oklahoma, as seismologist.

J. H. E. WARD, recently district geologist for the Mid-Continent Petroleum Corporation at San Antonio, Texas, has been transferred to Shreveport, Louisiana, to take charge of the district, including Mississippi, Alabama, Arkansas, and East Texas.

KARL HOWARD SCHILLING, research geologist with the Shell Oil Company, Inc., Houston, Texas, died on July 17, at the age of 51 years. He had been with the Shell 25 years.

QUENTIN SINGEWALD, of the University of Rochester, New York, has returned from field in Colombia and Venezuela extending over 2 years for the Metals and Minerals Division of the Foreign Economic Administration.

F. N. BOSCO, petroleum engineer and geologist, 2166 South Washington Street, Denver, Colorado, has returned to professional practice, after completing 34 months of service in the Army Engineers.

Captain GEORGE Y. MCCOY, of Palestine, Texas, is in the Corps of Engineers, Army of the United States.

Major JOHN D. MOODY, of the Gulf Oil Company, Shreveport, Louisiana, is in the Marines.

Lieutenant LEE ALLEN LATTA, of 2414 North Shartel, Oklahoma City, Oklahoma, is in the Navy.

GEORGE B. SOMERS, of Houston, Texas, has left the General Geophysical Company to become seismic party chief with the Yegua Corporation.

Lieutenant (j.g.) FLAVY E. DAVIS, of the Gulf Oil Corporation, Houston, Texas, is at the Fleet Photo Laboratory, Casco Bay, Portland, Maine.

Captain RICHARD O. STONE, of Alhambra, California, may be addressed: AAFBS, Big Spring, Texas.

EDWARD B. WALKER, III, of Tampa, Florida, is in the engineer section of the Army.

Captain ROBERT M. BEATTY, of Houston, Texas, is in the engineer section of the Army.

SIDON HARRIS was recently named president of the Southern Geophysical Company with main offices in the Sinclair Building, Fort Worth, Texas. He has been associated with the geophysical industry for 12 years, of which 10 were with the Stanolind Oil and Gas Company. PAUL H. LEDYARD, also with the Stanolind for 10 years, is seismograph supervisor for the Southern Geophysical Company.

Major H. E. SUFFIELD, of Woodward, Oklahoma, is on the Army General Staff Corps.

DON J. MCMULLEN is with the Heiland Research Corporation, 630 Giddens-Lane Building, Shreveport, Louisiana.

W. E. BAKKE, petroleum geologist with the First National Bank in St. Louis, has been transferred from St. Louis to San Antonio, Texas, where his address is 119 Seeling Avenue.

D. J. FLESH is managing partner of the Jefferson Oil and Gasoline Company, Jefferson, Texas.

Major LOUIS HOWARD HARING, JR., formerly with the Stanolind Oil and Gas Company, San Antonio, Texas, is in the Army Air Forces.

Lieutenant E. H. TOLLEFSON of the Hope Natural Gas Company, Clarksburg, West Virginia, is in the U. S. Naval Reserve. His address is T.A.I.C., N.A.S., Anacostia, D. C.

CHARLES LAURENCE BAKER, while on the Faculty of A. & M. College of Texas, College Station, Texas, wrote an article, "Geology, Climate, and Soils of Texas," published in *Proceedings* of the Texas Academy of Science, Vol. 27 (October, 1944), pp. 181–87. Baker is now in the employ of The Texas Company, Los Angeles, California.

CLIFFORD ADAMS of Rockville, Indiana, has accepted appointment as assistant professor of geology on the faculty of Hanover College, effective August 1. He specialized in sedimentation and stratigraphy at the University of Iowa where he received his Ph.D. degree. Adams was a Lieutenant in World War II.

WENDELL S. JOHNS has resigned from The Texas Company after 11 years of geological work with the company, and has opened his own office as consulting petroleum geologist at 600 Bitting Building, Wichita, Kansas.

M. KING HUBBERT has been named associate director of exploration and production for the Shell Oil Company, Inc., at Houston, Texas. He was previously senior geophysicist with the Shell.

GLEN M. RUBY, vice-president of United Engineering Corporation, S. A., was in the United States in August. He has been engaged in exploration and development at Punta Arenas, Chile, for several years.

Oil group meetings scheduled for October are the following: American Association of Oil Well Drilling Contractors, Oklahoma City, Oklahoma, October 1–2; Texas Mid-Continent Oil and Gas Association, Rice Hotel, Houston, Texas, October 4–6; Independent Petroleum Association of America, Tulsa, Oklahoma, October 15–17.

The papers composing the symposium, "The Age of the Saline Series of the Salt Range of the Punjab," which was held at Poona on December 29 and 30, 1944, under the joint auspices of the National Academy of Sciences of India and the Indian Academy of Sciences, were published in the *Proceedings* of the National Academy, Volume 14, Part 6, Section B, issued in May, 1945. Separate copies of the symposium number may be had from the General Secretary, National Academy of Sciences, c/o Department of Botany and Geology, University of Lucknow, U. P., India. The price, including postage, is Rs. 4/8 (India), Rs. 5 (foreign). The symposium will be continued at a joint meeting of the two Academies, to be held at Udaipur in December, 1945. All geologists interested in the subject are invited to attend and contribute papers, which will be published in the *Proceedings* of the National Academy of Sciences. Colleagues who expect to be able to attend and desire arrangements to be made for their accommodation are requested to inform the undersigned. It is hoped that prior to the date of the meeting it will be possible to arrange for a joint excursion to some of the critical sections in the Salt Range. Suggestions in this connection are invited. It is requested that, as far as practicable, written communications intended for advance printing should be posted so as to reach the undersigned before the middle of October. Any supplementary notes contributed in the light of the excursion may be sent in later and will also be printed.

B. SAHNI

Department of Botany and Geology,
University of Lucknow (U.P.)

PROFESSIONAL DIRECTORY

CALIFORNIA

COLORADO

ILLINOIS

GEOLOGICAL AND GEOPHYSICAL SOCIETIES

COLORADO

ROCKY MOUNTAIN ASSOCIATION OF PETROLEUM GEOLOGISTS
DENVER, COLORADO

President - - - - - - - - - J. J. Zorichak
Petroleum Administration for War
First National Bank Building
1st Vice-President - - - - John Vanderwilt
Climax Molybdenum Company
2nd Vice-President - - - - Max L. Krueger
Union Oil Company of California
Secretary-Treasurer - - - - Robert McMillan
Frontier Refining Company
First National Bank Building

Luncheons every Friday noon, Cosmopolitan Hotel. Evening dinner (6:15) and program (7:30) first Monday each month or by announcement, Cosmopolitan Hotel.

ILLINOIS

ILLINOIS GEOLOGICAL SOCIETY

President - - - - - - - - - Lee C. Lamar
Carter Oil Company, Box 568, Mattoon

Vice-President - - - - - - - Jack Hirsch
The Texas Company, Mattoon

Secretary-Treasurer - - - - - Gene Gaddess
Pure Oil Company, Olney

Meetings will be announced.

INDIANA-KENTUCKY

INDIANA-KENTUCKY GEOLOGICAL SOCIETY
EVANSVILLE, INDIANA

President - - - - - - - - Stanley G. Elder
Sun Oil Company

Vice-President - - - - - Hillard W. Bodkin
The Superior Oil Company

Secretary-Treasurer - - - - - Jess H. Hengst
Barnsdall Oil Company

Meetings will be announced.

KANSAS

KANSAS GEOLOGICAL SOCIETY
WICHITA, KANSAS

President - - - - - - - - - Virgil B. Cole
Gulf Oil Corporation
Vice-President - - - - - - - Laurence C. Hay
Consulting Geologist, 402 Union National Bank Building
Secretary-Treasurer - - - Edward A. Huffman
J. M. Huber Corporation, 407 First National Bank Building

Regular Meetings: 7:30 P.M., Geological Room, University of Wichita, first Tuesday of each month. The Society sponsors the Kansas Well Log Bureau, 412 Union National Bank Building, and the Kansas Well Sample Bureau, 137 North Topeka.

LOUISIANA

NEW ORLEANS GEOLOGICAL SOCIETY
NEW ORLEANS, LOUISIANA

President - - - - - - - - - Dean F. Metts
Humble Oil and Refining Company
1405 Canal Bldg.
Vice-President and Program Chm. - B. E. Bremer
The Texas Company, P.O. Box 252
Secretary-Treasurer - - - R. R. Copeland, Jr.
The California Company, 1818 Canal Bldg.

Meets the first Monday of every month, October-May inclusive, 7:30 P.M., St. Charles Hotel. Special meetings by announcement. Visiting geologists cordially invited.

LOUISIANA

THE SHREVEPORT GEOLOGICAL SOCIETY
SHREVEPORT, LOUISIANA

President - - - - - - - - - T. H. Philpott
Carter Oil Company, Box 1739
Vice-President - - - - - Van D. Robinson
Atlantic Refining Company
Secretary-Treasurer - - - - - - W. E. Wallace
Sohio Petroleum Corporation, Atlas Building

Meets the first Monday of every month, September to May, inclusive, 7:30 P.M., Criminal Court Room, Caddo Parish Court House. Special meetings and dinner meetings by announcement.

LOUISIANA

SOUTH LOUISIANA GEOLOGICAL SOCIETY
LAKE CHARLES, LOUISIANA

President - - - - - - - - Max Bornhauser
Continental Oil Co., Box 569, Lafayette
Vice-President - - - - - - A. Lyndon Morrow
Magnolia Petroleum Co., Box 872
Secretary - - - - - - - - Bruce M. Choate
Atlantic Refg. Co., Box 895
Treasurer - - - - - - - - P. F. Haberstick

Meetings: Dinner and business meetings third Tuesday of each month at 7:00 P.M. at the Majestic Hotel. Special meetings by announcement. Visiting geologists are welcome.

MICHIGAN

MICHIGAN GEOLOGICAL SOCIETY

President - - - - - - - Kenneth K. Landes
University of Michigan, Ann Arbor
Vice-President - - - - - - - - T. J. Weaver
Michigan Consolidated Gas Co., Grand Rapids
Secretary-Treasurer - - - Manley Osgood, Jr.
Cities Service Oil Co., Box 149, Mt. Pleasant
Business Manager - - - Harry J. Hardenberg
Michigan Geological Survey
Capitol Savings and Loan Bldg., Lansing

Meetings: Bi-monthly from November to April at Lansing. Afternoon session at 3:00, informal dinner at 6:30 followed by discussions. (Dual meetings for the duration.) Visiting geologists are welcome.

MISSISSIPPI

MISSISSIPPI GEOLOGICAL SOCIETY
JACKSON, MISSISSIPPI

President - - - - - - - - - - - J. B. Storey
Union Producing Company

Vice-President - - - - - Frederic F. Mellen
Mellen & Monsour
Box 2571, W. Jackson Sta.

Secretary-Treasurer - - - - - J. B. Wheeler
Stanolind Oil and Gas Company

Meetings: First and third Thursdays of each month, from October to May, inclusive, at 7:30 P.M., Edwards Hotel, Jackson, Mississippi. Visiting geologists welcome to all meetings.

OKLAHOMA

ARDMORE GEOLOGICAL SOCIETY
ARDMORE, OKLAHOMA

President - - - - - - - - Stanford L. Rose
The California Company, 618 Simpson Bldg.

Vice-President - - - - - Maynard P. White
Gulf Oil Corporation, Box 30

Secretary-Treasurer - - Hamilton M. Johnson
Schlumberger Well Surveying Corp., Box 747

Dinner meetings will be held at 7:00 P.M. on the first Wednesday of every month from October to May, inclusive, at the Ardmore Hotel.

OKLAHOMA

OKLAHOMA CITY GEOLOGICAL SOCIETY
OKLAHOMA CITY, OKLAHOMA

President - - - - - - - - Ralph L. Fillmore
Anderson-Prichard Oil Co.
1000 Apco Tower

Vice-President - - - - - Roy D. McAninch
Stanolind Oil and Gas Company
Box 1633

Secretary-Treasurer - - - - - Carl A. Moore
Carter Oil Company
1300 Apco Tower

Meetings: Technical program each month, subject to call by Program Committee, Oklahoma City University, 24th Street and Blackwelder. Luncheons: Every second Thursday, at 12:00 noon. Skirvin Hotel.

TULSA GEOLOGICAL SOCIETY
TULSA, OKLAHOMA

President - - - - - - - - - A. N. Murray
University of Tulsa

1st Vice-President - - - - Paul E. Fitzgerald
Dowell, Inc., Kennedy Building

2nd Vice-President - - - - - Oscar Hatcher
Helmerich & Payne, Inc., 415 Philtower

Secretary-Treasurer - - - Glenn R. V. Griffith
U. S. Geological Survey, Box 311

Editor - - - - - - - - Charles J. Deegan
Oil and Gas Journal, Box 1260

Meetings: First and third Mondays, each month, from October to May, inclusive at 8:00 P.M., University of Tulsa, Kendall Hall Auditorium. Luncheons: Every Tuesday (October-May), Bradford Hotel.

SHAWNEE GEOLOGICAL SOCIETY
SHAWNEE, OKLAHOMA

President - - - - - - - - - - - Allen Ehlers

Vice-President - - - - - - - John P. Lukens
Oklahoma Seismograph, 1103 North Philadelphia

Secretary-Treasurer - - - - Marcelle Mousley
Atlantic Refining Company, Box 169

Meets the fourth Thursday of each month at 8:00 P.M., at the Aldridge Hotel. Visiting geologists welcome.

TEXAS

DALLAS PETROLEUM GEOLOGISTS
DALLAS, TEXAS

President - - - - - - - - - Henry C. Cortes
Magnolia Petroleum Company

Vice-President - - - - - - - Cecil H. Green
Geophysical Service, Inc.

Secretary-Treasurer - - - - Willis G. Meyer
DeGolyer and MacNaughton, Continental Building

Executive Committee - - - Henry J. Morgan
Atlantic Refining Company

Meetings: Monthly luncheons by announcement. Special night meetings by announcement.

TEXAS

CORPUS CHRISTI GEOLOGICAL SOCIETY
CORPUS CHRISTI, TEXAS

President - - - - - - - - - - - Ira H. Stein
Bridwell Oil Company, Alice, Texas

Vice-President - - - - Henry D. McCallum
Humble Oil and Refining Company

Secretary-Treasurer - - - - Elsie B. Chalupnik
Barnsdall Oil Company, 604 Driscoll Building

Regular luncheons, every Wednesday, Petroleum Room, Plaza Hotel, 12:05 P.M. Special night meetings, by announcement.

EAST TEXAS GEOLOGICAL SOCIETY
TYLER, TEXAS

President - - - - - - - - - J. H. McGuirt

Vice-President - - - - - R. M. Trowbridge
Trowbridge Sample Service

Secretary-Treasurer - - - - - G. T. Buskirk
Stanolind Oil and Gas Company, Box 660

Meetings: Regular meetings at 7:30 P.M., the second Monday, each month, City Hall.

Luncheons: Noon, fourth Monday, each month, Blackstone Hotel.

TEXAS

FORT WORTH GEOLOGICAL SOCIETY

FORT WORTH, TEXAS

President - - - - - - Thomas B. Romine
Sinclair Prairie Oil Company, 901 Fair Building

Vice-President - - - - - William J. Nolte
Stanolind Oil and Gas Company, Box 1410

Secretary-Treasurer - - - Spencer R. Normand
Independent Exploration Company
2210 Ft. Worth Natl. Bank Bldg.

Meetings: Luncheon at noon, Hotel Texas, first and third Mondays of each month. Visiting geologists and friends are invited and welcome at all meetings.

NORTH TEXAS GEOLOGICAL SOCIETY

WICHITA FALLS, TEXAS

President - - - - - William Lloyd Haseltine
Magnolia Petroleum Co., Box 239

Vice-President - - - - Charles R. Canfield
Stanolind Oil and Gas Company
909 Hamilton Building

Secretary-Treasurer - - - - John R. Davis
Superior Oil Company, 807 Hamilton Building

Luncheons and evening programs will be announced.

WEST TEXAS GEOLOGICAL SOCIETY

MIDLAND, TEXAS

President - - - - - - - - F. H. McGuigan
Lion Oil Refining Company

Vice-President - - - - - Leo R. Newfarmer
Shell Oil Company, Inc.

Secretary-Treasurer - - - - - Alan B. Leeper
Honolulu Oil Corporation

Meetings will be announced.

WYOMING

WYOMING GEOLOGICAL ASSOCIATION

CASPER, WYOMING
P. O. Box 545

President - - - - - - - - - - C. J. Hares
The Ohio Oil Company

1st Vice-President - - - - - A. F. Barrett
General Petroleum Corporation

2nd Vice-President (Programs) - W. S. McCabe
Stanolind Oil & Gas Company

Secretary-Treasurer - - - - - R. M. Larsen
U. S. Geological Survey

Informal luncheon meetings every Friday, 12 noon, Townsend Hotel. Visiting geologists welcome. Special Meetings by announcement.

HOUSTON GEOLOGICAL SOCIETY

HOUSTON, TEXAS

President - - - - - - - - W. B. Milton, Jr.
Houston Oil Co. of Texas, Box 2412

Vice-President - - - - - - W. B. Moore
Atlantic Refining Company, Box 1346

Secretary - - - - - - - Charles H. Sample
J. M. Huber Corporation, 721 Bankers Mortgage Building

Treasurer - - - - - - - - Homer A. Noble
Magnolia Petroleum Company, Box 111

Regular meeting held the first and third Thursdays at noon (12 o'clock), Mezzanine floor, Texas State Hotel. For any particulars pertaining to the meetings write or call the secretary.

SOUTH TEXAS GEOLOGICAL SOCIETY

SAN ANTONIO, TEXAS

President - - - - - - - - Harvey Whitaker
1409 Milam Building

Vice-President - - - - - - George H. Coates
638 Milam Building

Secretary-Treasurer - - - - Marion J. Moore
Transwestern Oil Company, 1600 Milam Building

Meetings: One regular meeting each month in San Antonio. Luncheon every Monday noon at Milam Cafeteria, San Antonio.

WEST VIRGINIA

THE APPALACHIAN GEOLOGICAL SOCIETY

CHARLESTON, WEST VIRGINIA
P. O. Box 2605

President - - - - - - Douglas Rogers, Jr.
South Penn Natural Gas Company, Parkersburg

Vice-President - - - - - Veleair C. Smith
Kanawha Valley Bank Building

Secretary-Treasurer - - - - W. B. Maxwell
United Fuel Gas Company, Box 1273

Editor - - - - - - - - H. J. Simmons, Jr.
Godfrey L. Cabot, Inc., Box 1473

Meetings: Second Monday, each month, except June July, and August, at 6:30 P.M., Kanawha Hotel.

THE SOCIETY OF EXPLORATION GEOPHYSICISTS

President - - - - - - - Henry C. Cortes
Magnolia Petroleum Co., Dallas, Texas

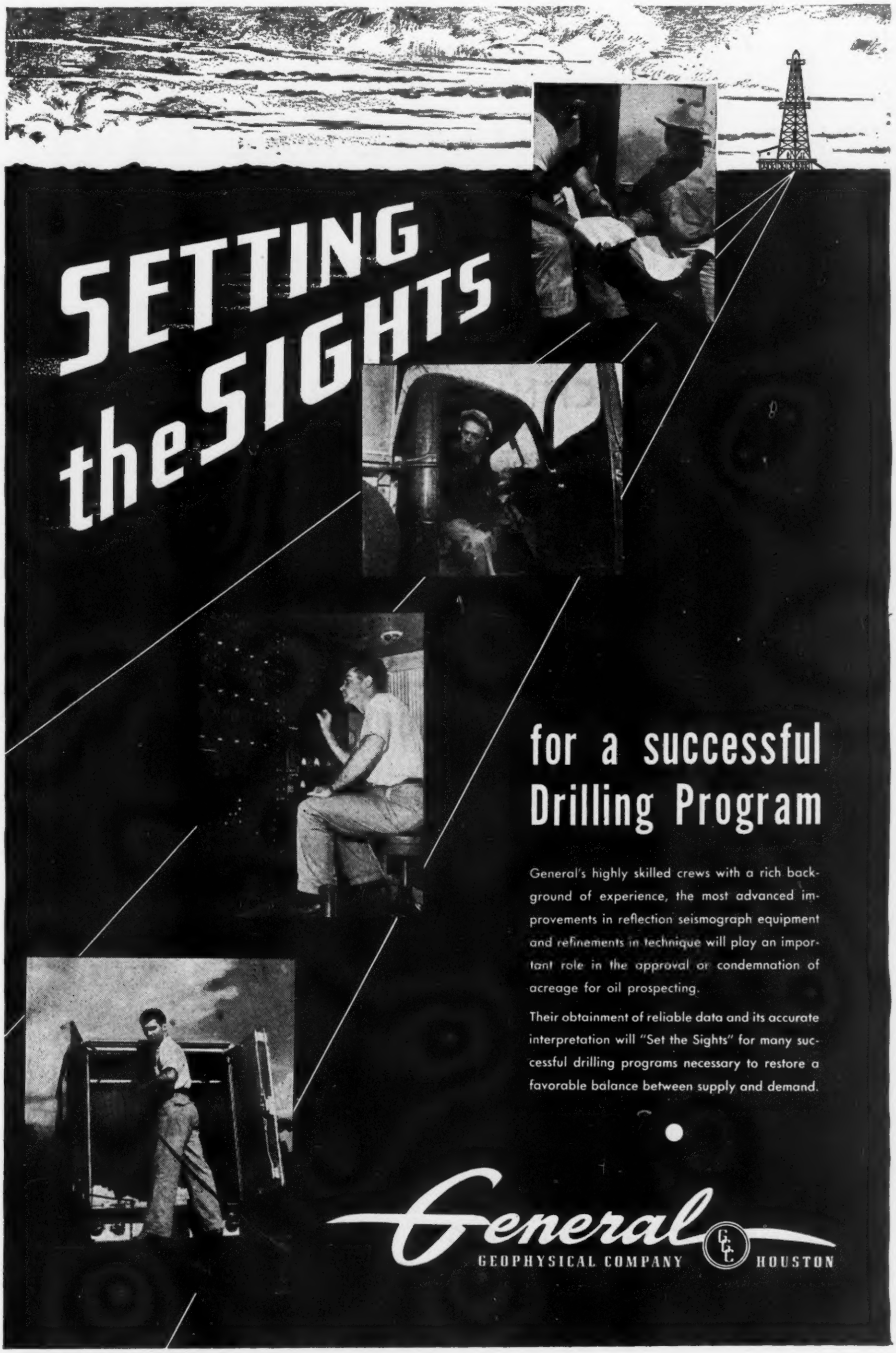
Vice-President - - - - - - - J. J. Jakosky
University of Southern California, Los Angeles

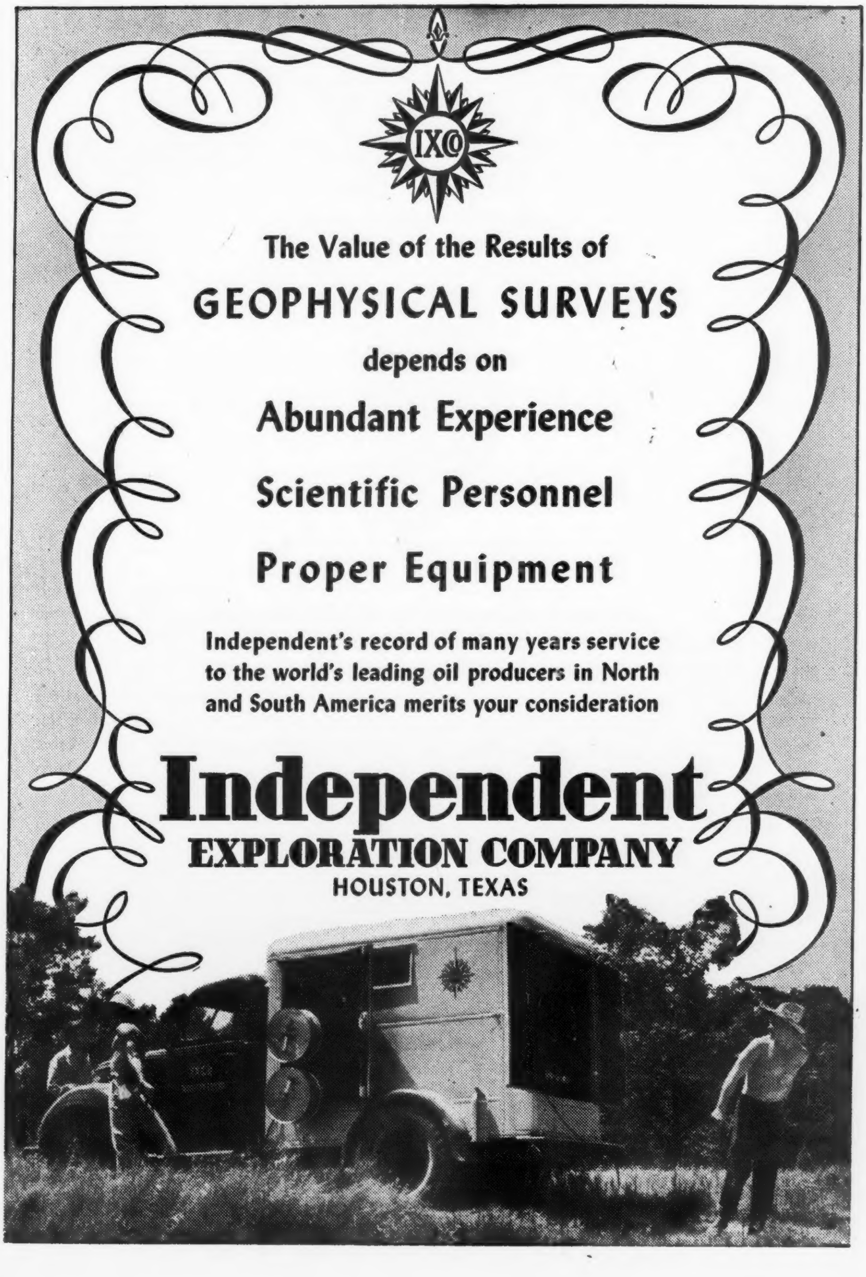
Editor - - - - - - - - - - L. L. Nettleton
Gulf Research Laboratory, Pittsburgh, Pennsylvania

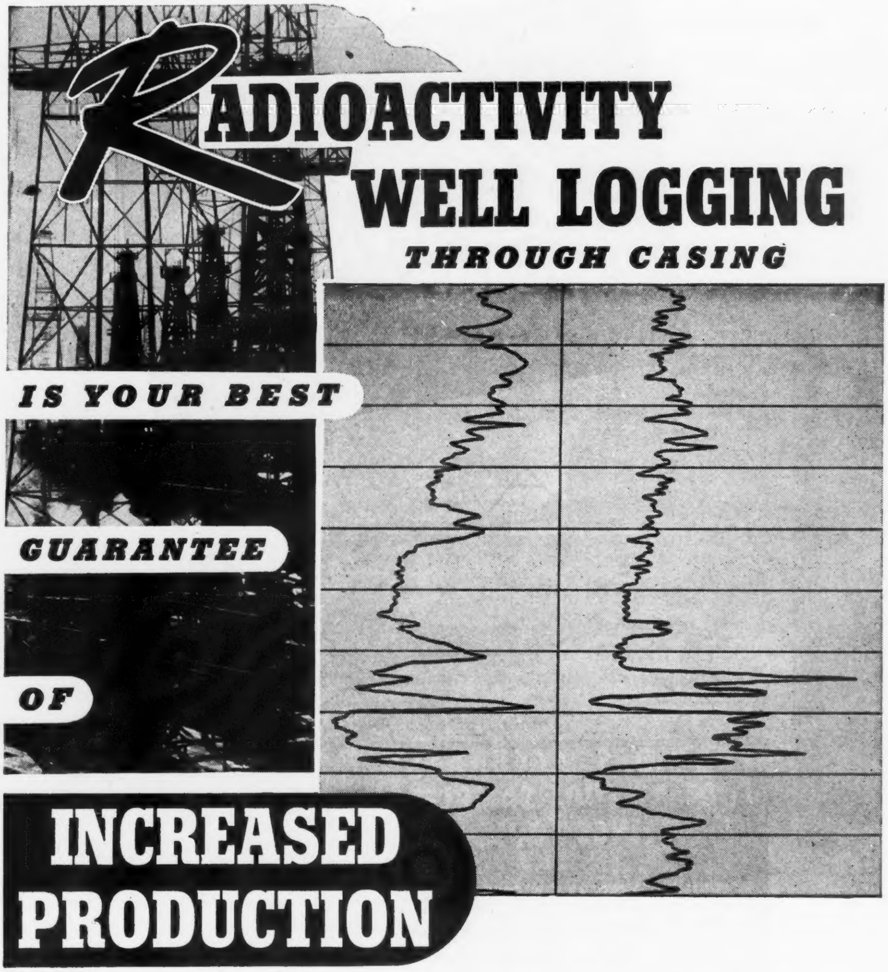
Secretary-Treasurer - - - - Cecil H. Green
Geophysical Service, Inc., 1311 Republic Bank Building, Dallas, Texas

Past-President - - - William M. Rust, Jr.
Humble Oil & Refining Company, Houston

Business Manager - - - - - - - E. Stiles
Hamilton, Texas


SETTING the SIGHTS
for a successful Drilling Program
General's highly skilled crews with a rich background of experience, the most advanced improvements in reflection seismograph equipment and refinements in technique will play an important role in the approval or condemnation of acreage for oil prospecting.
Their obtainment of reliable data and its accurate interpretation will "Set the Sights" for many successful drilling programs necessary to restore a favorable balance between supply and demand.
General
GEOPHYSICAL COMPANY
HOUSTON


IXCO
The Value of the Results of
GEOPHYSICAL SURVEYS
depends on
Abundant Experience
Scientific Personnel
Proper Equipment
Independent's record of many years service
to the world's leading oil producers in North
and South America merits your consideration
Independent
EXPLORATION COMPANY
HOUSTON, TEXAS

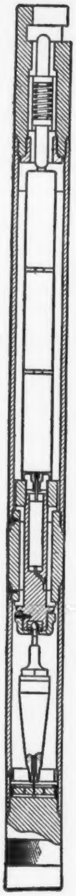

RADIOACTIVITY
WELL LOGGING
THROUGH CASING
IS YOUR BEST
GUARANTEE
OF
INCREASED
PRODUCTION


THE Thompson SHALE SEPARATOR AND SAMPLE MACHINE
SAMPLE MACHINE
PROVIDES ACCURATE FOOT BY FOOT SAMPLES OF CUTTINGS TOO!
In addition to thoroughly reconditioning your drilling mud, the Thompson also provides accurate foot by foot samples of cuttings. The entire machine operates from flow of mud. IMPORTANT — Remember, Thompson pioneered the self-motivated Shale Separator. Its outstanding performance is due to years of development.
THOMPSON TOOL CO.
IOWA PARK, TEXAS
THE SHALE SEPARATOR THAT Really HANDLES THE LOAD
KEEPS DRILLING MUD CLEAN — PROVIDES TRUE SAMPLES OF CUTTINGS

Fe
all
thi
mu
the
Th
Fe
ye
lor
for
Th
im
by
fin
gr
Fe

E EA-SY C Inclinometer

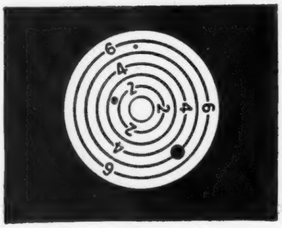
Gives a True Record



Correct recording with any inclinometer can be only obtained when the pedulum is *at rest*.

Not this — But this

The E-C Inclinometer is self-checking, making records only when its pendulum is at rest. No timing devices are necessary. It operates automatically as soon as the plumb bob comes to rest for a period of at least one minute. Multiple records can be made during one round trip.

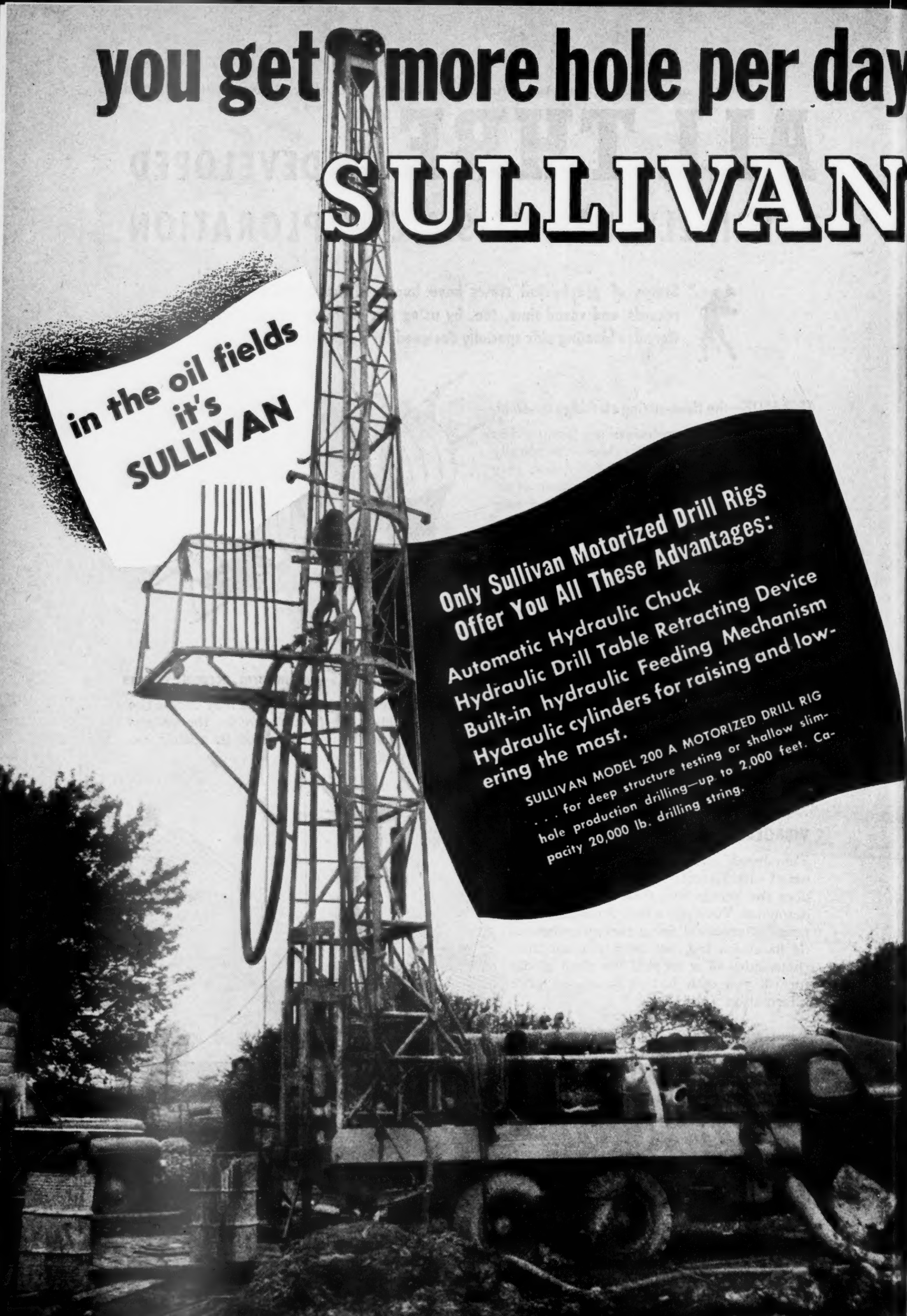


By means of electro chemical action on a paper disc which does not require development, nor is sensible to light, a record of the angle of inclination is made. A small round, white dot indicates the angle of inclination. The size of this dot is determined by the period of resting. The longer the period, the larger the dot. The depths at which multiple records have been taken can be identified from the size of the dots.

SPERRY-SUN

SPERRY-SUN WELL SURVEYING CO.

Offices: Philadelphia, Pa.; Houston, Corpus Christi, Marshall, Odessa, Texas; Lafayette, La.; Long Beach, Bakersfield, Calif.; Oklahoma City, Okla.; Casper, Wyo.



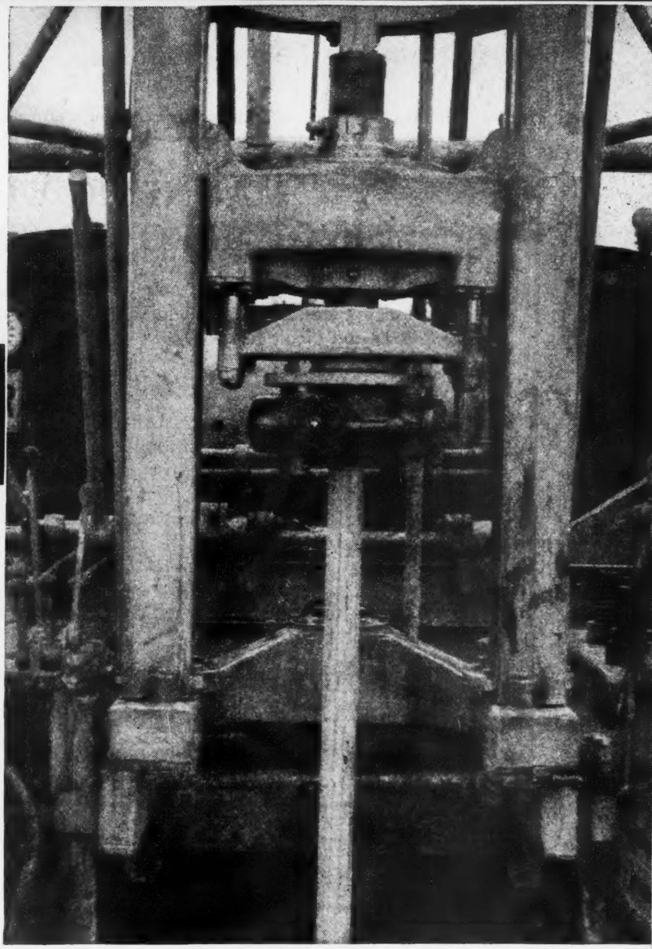
you get more hole per day
SULLIVAN
in the oil fields
it's
SULLIVAN
Only Sullivan Motorized Drill Rigs
Offer You All These Advantages:
Automatic Hydraulic Chuck
Hydraulic Drill Table Retracting Device
Built-in hydraulic Feeding Mechanism
Hydraulic cylinders for raising and lowering the mast.
SULLIVAN MODEL 200 A MOTORIZED DRILL RIG
. . . for deep structure testing or shallow slim-hole production drilling—up to 2,000 feet. Capacity 20,000 lb. drilling string.

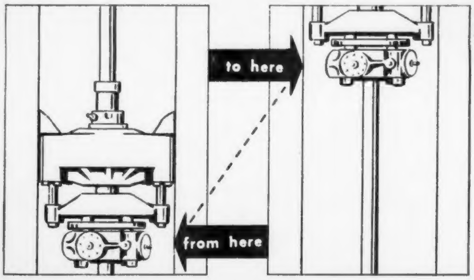
with the

200 A

motorized drill rig

• TIME SAVED — when *looking for a structure* or when drilling for shallow slim-hole production—means more hole per day and lower drilling costs. That's why Sullivan Rigs are so popular in oil fields the world over. Automatic chuck, a hydraulic drill table retracting device, a built-in hydraulic feeding mechanism and hydraulic cylinders for raising and lowering the mast . . . are some of the exclusive Sullivan features that save you time, give you more hole per day at lower costs. For details, write your nearest Sullivan branch office. **Sullivan Machinery Company — General Offices — Michigan City, Indiana. In Canada: Canadian Sullivan Machinery Company, Ltd., Dundas, Ontario.**





. . . in a matter of seconds!

You can re-chuck with a Sullivan Rig IN A MATTER OF SECONDS! It's the automatic chuck that does the trick. With this exclusive Sullivan feature hand set screws are eliminated . . . rods are released or gripped by hydraulic feed mechanism without stopping rotation. A time-saver found only on Sullivan Motorized Drill Rigs!

SULLIVAN

World's Largest Manufacturers of Core Drills and Motorized Drill Rigs

OFFICES

Chicago, 307 N. Michigan Ave.
Denver, 1815 California St.
New York, 30 Church St.
Dallas, 1914 Commerce St.
Los Angeles, 2900 Santa Fe Ave.
San Francisco, 145 10th St.
St. Louis, 2639 Locust St.

PRODUCTS

Water Swivels — Traveling Blocks — Fishtail and Drag Bits — Core Barrels — Portable and Stationary Air Compressors — Rock Drills — Portable Hoists


WE DEPEND ON THE REED FOR ALL OUR CORING JOBS!
REED 'BR' Wire Line CORE DRILL
Operators in every part of the world "Core with Confidence" with the Reed "BR" Wire Line Coring-Drilling Bit on bottom. They have learned through practice and experience that for positive results in hard or soft formations they can depend on Reed Core Drills.
COMPLETE CORING SERVICE
The REED KOR-KING CONVENTIONAL
The REED "BR" WIRE LINE
The REED STREAMLINED KOR-KING FOR SMALL HOLE DRILLING
HARD AND SOFT FORMATION HEADS INTERCHANGEABLE
REED ROTARY DRILLING TOOLS
SPEED · ECONOMY · DURABILITY
REED ROLLER BIT COMPANY
POST OFFICE BOX 2119
HOUSTON, TEXAS